THE ONTARIO HIGH SCHOOL LABORATORY MANUAL IN PHYSICS

REVISED EDITION

AUTHORIZED BY
THE MINISTER OF EDUCATION FOR ONTARIO

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THE ONTARIO HIGH SCHOOL LABORATORY MANUAL IN PHYSICS

BY

F. W. MERCHANT, M.A., D.PAED., LL.D.

Chief Director of Education for Ontario

AND

C. A. CHANT, M.A., PH.D.

Professor of Astrophysics,
University of Toronto

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PREFACE

This LABORATORY MANUAL is designed to accompany the HIGH SCHOOL PHYSICS.

In preparing the present edition many alterations and additions have been made with the object of fitting the experiments described herein more closely to the treatment of the various subjects in the text-book, and also of rendering the book more suitable to be placed in the hands of the students and used by them with the least amount of direction from the teacher.

The experiments in the book may be divided into three classes. First, those which are qualitative or simply illustrative in nature and those which require rather more elaborate apparatus. It is intended that the teacher shall perform these himself, at the same time discussing them with the class as he proceeds. These are marked with a single star (*) before the number of the experiment. Then there are a few which are intended chiefly for Upper School students. These are indicated by two stars (**). The remainder, which make up the larger portion of the book, are to be performed by the students working singly or in pairs. The apparatus for them is simple and the instructions have been made as plain and explicit as possible.

At the front of the book is an introductory chapter giving general instructions to the student; at the back is an appendix containing suggestions for teachers and a detailed list of apparatus required for the experiments to be performed in concert by the students. It also contains a series of tables of physical constants taken from the *Smithsonian Physical Tables.* This volume, or one similar to it, should be in every physical laboratory.

Many of the improvements introduced in this edition are due to Mr. George A. Cline, M.A., Instructor in Physics in the University of Toronto Schools, Toronto, whose good judgment and wide experience in teaching the subject have been invaluable. In addition, many important corrections and suggestions have been received from Mr. George F. Rogers, B.A. Inspector of High Schools, and Mr. G. K. Mills, B.A., Inspector of Continuation Schools. From their long and intimate connection with secondary schools, large and small, they have been able to offer many criticisms of a useful and practical nature.

TORONTO, JUNE, 1924

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Part VII—Electricity and Magnetism

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INTRODUCTION

Information for Students

The Value of Laboratory Work

The ancient Greeks, who lived more than two thousand years ago, knew many of the fundamental facts of physical science and yet they contributed but slightly to its advancement. Why was this? They were clever, acute thinkers, but they possessed little or no aptitude for observing and experimenting. They were content to speculate upon the causes of things which they saw, but did not care to put their theories to the proof.

The various laws of physics and their practical applications, such as in the telephone, radio, electric lighting, the gasoline engine, the huge turbine and the mighty dynamo, have been developed by careful, systematic, persistent experimentation.

The object of the work in the physical laboratory is to learn how to make experiments and then to draw the proper conclusions.

Further, there is a wide difference between information crammed into the mind in set phrases out of a text-book, and a living knowledge of visible things acquired by one's own conscious efforts. In the laboratory you are given a definite problem to investigate and are expected to proceed methodically to its solution. By experience you learn that apparatus must be handled carefully, observations made accurately and results recorded fully. After performing a number of the experiments you will be able to appreciate some of the difficulties encountered by the pioneer scientists and to realize what we owe to their patience, devotion and skill.

How to Proceed

The instructions given with each experiment serve as a guide to the solution of the problem proposed, with the least possible waste of time and energy.

These instructions should be read carefully before starting the actual experimenting. "Hasten slowly!" Being in a hurry to begin often leads one to overlook some important part of the operations and hence to reach an unsatisfactory result.

Concise but complete notes of the measurements and the observations made should be kept by *each* person during the progress of the work. Write them down at once!

Take all measurements with the greatest care. Even when one has done his best, he will find that he has fallen far short of absolute accuracy. A human being need never expect to reach perfection; there will always be some accidental error.

But in every case, record the observations made and the result deduced exactly as they are secured. An idea of what one expects to get should not be allowed to influence what is actually obtained.

Care of Apparatus

Scientific apparatus is costly and has to serve a school for many years. Make it a matter of honour to leave the apparatus clean and in good condition. Never do anything to deface or otherwise injure it.

Laboratory Note Books

While notes of observations are to be made during the experiment, the full record of the work is usually written out after completing it. For this purpose a loose-leaf note-book is most satisfactory.

Make the report neat, concise and clear, so that when any one else reads it over he will understand what you set out to do and what you actually accomplished.

The matters to be included in the record may be listed thus: —

1. Name of student and form in school.
2. Number and purpose of the experiment.
3. List of apparatus used. (This may be omitted, at the option of the teacher.)
4. Description of procedure. This should be in the student's own words in sufficient detail to enable him to recall the experiment easily when he reviews the work.
5. Observations, (tabulated when possible).
6. Calculation of numerical results (if any). The various steps in the calculation should be so clearly set forth that any one examining the report should be able to understand the process of reasoning by which the result was obtained.
7. Conclusions which can be drawn from the experiment.
8. Diagrams of apparatus, electrical circuits, etc.

An actual report by a high school student will be found on the next two pages. This is intended to be only suggestive. Perhaps you can improve on it. At any rate use your own mind and do your best.

Experiments which are marked with one star (*) are intended to be demonstrations by the teacher; those with two stars (**) are for Upper School students; the remainder are for simultaneous performance by the students working singly or in pairs.

SPECIMEN REPORT

Physics Report

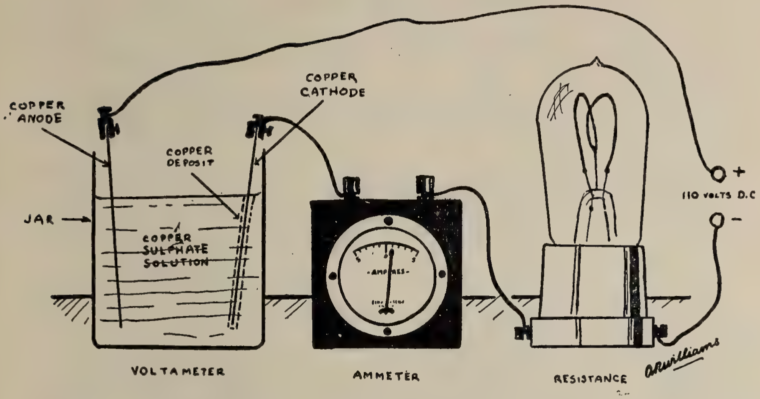
Form II — A.R. Williams

Purpose:—
To determine the current flowing in an electrical circuit by means of a copper voltameter.

Apparatus:—
Two copper plates, a solution of copper sulphate, a glass jar, an ammeter, a lamp resistance, some wire and a piece of emery cloth.

Method:—
The copper plate which was to be the cathode was cleaned and weighed. The apparatus was then arranged as in the diagram and the current turned on for 10 minutes. The cathode was then carefully removed, washed in water and dried in the warm air over a gentle bunsen flame, after which it was again weighed. The current flowing in the circuit was determined by means of the following data and checked with the current indicated by the meter.

1 Ampere in 1 second deposits .000328 gms of copper.
The actual amount of copper deposited.
The actual number of seconds.



Observations –

The cathode weighed before plating 23.511 gms
After plating it weighed 23.699 grams
Therefore .188 gms of copper were deposited
The current was run for 600 seconds

Conclusions –

Since .188 gms were deposited on cathode in 600 secs
Therefore $\frac{.188}{600}$ grams were deposited in 1 second

And since 1 amp in 1 sec. deposits 000328 gms of copper
And in 1 second .000313 gms. were actually deposited
I conclude that $\frac{.000313}{.000328}$ or $\underline{\underline{.954}}$ amperes
were passing through the cell.

Part I.—Mensuration, Units, Density

Experiment 1.—To determine the number of centimetres in one inch.

Apparatus:—Rule graduated in inches and centimetres, sharp-pointed pencil or pin.

Method.—Place the edge of the rule on a sheet of paper so that the inch divisions are touching the paper and mark off two points exactly two inches apart (Fig. 1). In doing this do not use the end division of the rule as it is frequently incorrect. Then measure the distance between these points in centimetres. If the reading comes between two millimetre marks, estimate the fraction in tenths. This will give the number of centimetres in two inches to two places of decimals. Next, calculate (by division) the number of centimetres in one inch.

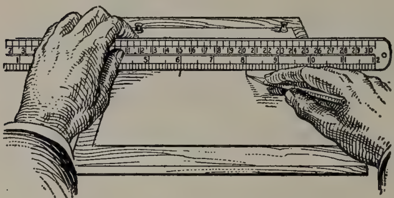


Fig. 1.—Comparing inches and centimetres.

Repeat using points three, four and five inches apart. Tabulate results as follows:—

Results

Inches	Centimetres	Cm. in 1 In.
2	....	....
3	....	....
4	....	....
5	....	....
	Average	....

Write down your conclusion.

Experiment 2.—To construct a graph to show the relation between inches and centimetres.

Apparatus:—Piece of squared paper, pencil and rule.

Method.—Let each large division measured to the right of OY (Fig. 2), *represent* one inch, and let each large division measured up from OX represent one centimetre.

Mark along OX and OY, 1, 2, 3, etc., as in the diagram.

From Experiment 1 we know that 1 inch equals 2.54 cm., 2 inches 5.08 cm., 3 inches 7.62 cm., etc.

From O travel along OX to the 1-inch mark and then travel up the vertical line at the 1-inch mark until a point is reached at a distance from OX representing 2.54 cm. At this point make a dot with the pencil.

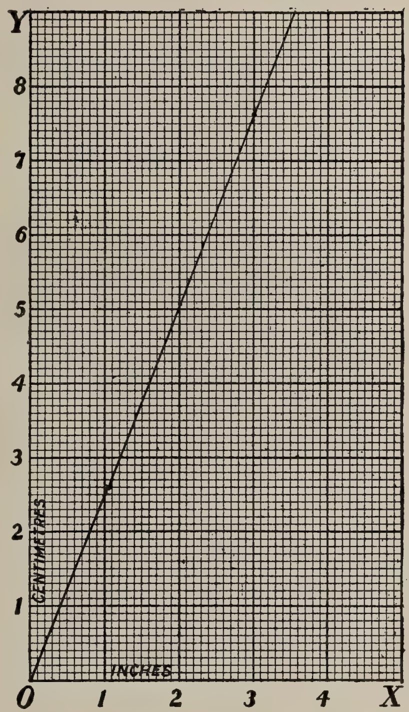


Fig. 2.—Graph showing relation between inches and centimetres.

Next travel up from the 2-inch mark a distance representing 5.08 cm. and make another dot. Continue similarly until the limits of the sheet of squared paper are reached.

Now, by means of a line, join all the points obtained. If the work has been done accurately the line will be straight, and it will represent graphically the relation between inches and centimetres.

From the graph determine the number of centimetres in 2.4, 3.2, 5.8 and 7.6 in. and the number of inches in 2.3, 4.7, 9.6 and 10.4 cm.

Graphs are very useful in expressing visually many physical laws and relations. OX and OY are called the axes of reference. Distances measured in the direction OX are known as *abscissas* and those in the direction OY as *ordinates*.

Experiment 3.—To determine experimentally the value of π (the ratio of the circumference to the diameter of a circle).

Apparatus:—Accurately-made circular wooden or metal discs from 2 to 8 inches in diameter, large coins, or cylindrical cans; strips of thin paper; fine wire, such as florists use; metric rule.

(*a*) *Measure the Diameter.* *Method I.*—Lay the rule on a face of the disc so that the graduated edge lies along a diameter (Fig. 3), and adjust it so that one edge of the disc is exactly at one of the graduations on the stick. Then take the reading at the other edge of the disc, and by subtracting the two readings obtain the diameter. If the latter edge comes between two graduation marks, estimate the fraction in tenths, not in halves or thirds as we usually do. It is much simpler to work with decimals, and a little practice will enable one to estimate quickly the nearest tenth with considerable accuracy.

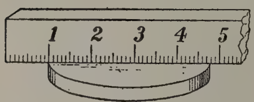


Fig. 3.—Measuring the diameter of a disc. Lay a graduated edge along a diameter.

Method II.—Two patterns of callipers are shown in Figs. 4 and 5. The upper ends of the instrument shown in Fig. 5 are for determining the inner diameter of a tube or a ring; the other ends are for measuring outside diameters. Adjust the callipers to the disc until it will just slip through the jaws. Then measure the distance between the jaws on the rule.

Measure five (or more) different diameters of the disc. As a final result take the average of all the measurements.

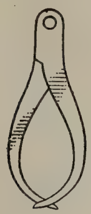


FIG. 4.—Callipers.

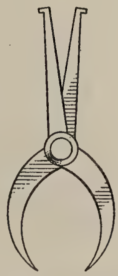


FIG. 5.—Callipers.

(*b*) *Measure the Circumference.* *Method I.*—Wrap a strip of paper tightly round the edge of the disc, and in the overlapping portion prick a *small* hole with a pin. Then spread the paper out on a table and, laying the metric rule on it, measure the distance between the two holes. This is the length of the circumference. Repeat the process and take the average of all measurements.

Method II.—Wind the fine wire one or more times—according to the size of the disc—about the circumference, and then measure the length of the wire by applying it to the rule. Take the mean of five measurements.

Repeat the measurements of diameter and circumference, using different discs, coins or cans.

Record the observations on each disc in a table, such as the following:—

FIRST DISC

TRIAL	DIAMETER	CIRCUMFERENCE	
		1st Method	2nd Method
1	......	......	......
2	......	......	......
3	......	......	......
4	......	......	......
5	......	......	......
Mean	......	......	......
Value of π		......	......

Why is it advisable to use discs of the sizes indicated rather than small ones, say 1 inch in diameter?

Experiment 4.—To find the area of a circle.

APPARATUS:—Compasses, squared paper, metric rule.

Method.—Draw a circle with radius 3 centimetres (or 1 inch if more convenient) on squared paper, (Fig. 6). The paper is usually divided into mm. or tenths of inches, and hence the area of a small square is 1 sq. mm. or $\frac{1}{100}$ sq. inch. Count the number of complete small squares in one quadrant of the circle; count also the number of incomplete squares in the quadrant and divide this number by 2*. Then add together the two numbers so obtained and from this calculate the area of the whole circle in sq. cm. or sq. in. (*Suggestion.*—First find the number of little squares in the large square *abcd*).

*Some of these incomplete squares will be greater than one-half and others less than one-half of a complete square; the average value of the area of an incomplete square will be approximately one-half.

Next find the area of the square on the radius, and divide this into the area of the circle.

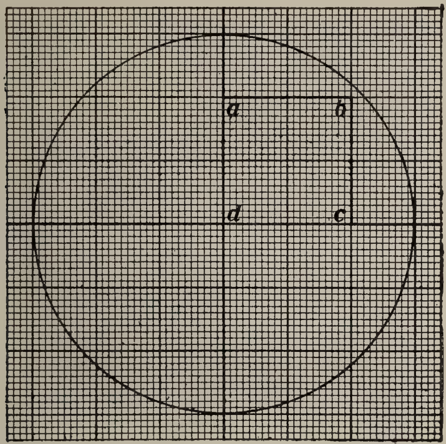


FIG. 6.—Finding the area of the circle by counting the full squares and the fractional parts.

Repeat, using circles 4 and 5 centimetres (or 2 and 3 inches) in radius, and tabulate your observations as follows:—

RADIUS OF CIRCLE	AREA OF CIRCLE	AREA OF SQUARE ON RADIUS	AREA OF CIRCLE / AREA OF SQ. ON RADIUS
3 cm.	...... sq. cm.	...... sq. cm.	......
4 "	...... "	...... "	......
5 "	...... "	...... "	......

Average ......

The area of a circle is πr^2 (π = 22/7 or 3.1416). Compare your result with this.

Experiment 5.—To find the volume of a cylinder by measurement, and to test the result by using an overflow can and a graduate.

APPARATUS:—Cylindrical block, callipers, metric rule, overflow can and a graduate.

Method.—Using the callipers and rule, find the average height and diameter of the block in cm., taking at least three measurements of each dimension.

Calculate the volume of the cylinder in c.c. from the formula $\pi r^2 h$ where r is the radius and h the height of the cylinder.

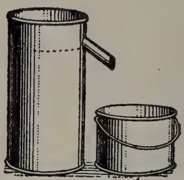


FIG. 7.—Overflow can.

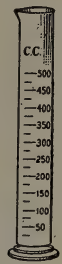


FIG. 8.—A graduate for finding volumes.

Next, place the finger over the spout of the overflow can (Fig. 7) and hold it under the tap until the water is above the level of the spout. Place the can on the table and let the excess water run out into a beaker. Empty this water into the sink. Now hold a graduate (Fig. 8) under the spout and lower the cylinder into the can slowly, until it is wholly immersed. (If the block is of wood it will have to be pushed under the water with a pin.) When the water stops running out of the spout, place the graduate on the table and take the reading. Water in a glass vessel curves up at the edge; it is the reading of the *lowest* part of the surface which must be observed. Take three readings of the water displaced and record your results as follows:—

READING	HEIGHT	DIAMETER	VOL. BY CALCULATION	VOL. BY DISPLACEMENT
1	......cm.	......cm.	from the average height and diameter	...... c.c.
2	...... "	...... "		...... "
3	...... "	...... "		...... "
AVERAGE	...... "	...... "	..... c.c.	...... "

Which method do you prefer? Why?

Experiment 6.—To find the volume of a sphere by measurement and to test the result by the displacement method.

Apparatus:—A hard rubber ball (or other sphere), callipers, rule, overflow can and graduate.

Method.—Using the callipers and rule, find the diameter of the sphere in cm., taking the average of at least three readings.

Calculate the volume in c.c. from the formula $\frac{4}{3}\pi r^3$, where r is the radius of the sphere.

Next find the volume by displacement (see Experiment 5). This should be repeated at least three times.

Record your results as follows:—

Average diameter of sphere ...... cm.
Volume by measurement ($\frac{4}{3}\pi r^3$) ...... c.c.
Average volume by displacement ...... c.c.

Experiment 7.—To construct a graduate.

Apparatus:—Piece of glass tubing of about 3 cm. diameter and 15 cm. height, rubber stopper, callipers, rule.

Method.—Cork one end of the tube as in Fig. 9, and find the average diameter of the tube by using the callipers and rule. Then calculate the area of the cross-section of the tube by using the formula, Area $= \pi r^2$.

Next compute (by division) how far up from the cork you would need to place marks reading 10 c.c., 20 c.c., 30 c.c., etc. Mark off these divisions on a strip of paper and secure it to the outside of the tube by rubber bands.

Fig. 9.–Tube used in making a simple graduate.

Test the graduate you have made by pouring into it volumes of water measured in another graduate.

Determination of Mass.—Mass is determined by means of the balance (Fig. 10). For description of balance, weights, etc., see TEXT-BOOK, § 12. In using the balance the following rules should be observed:

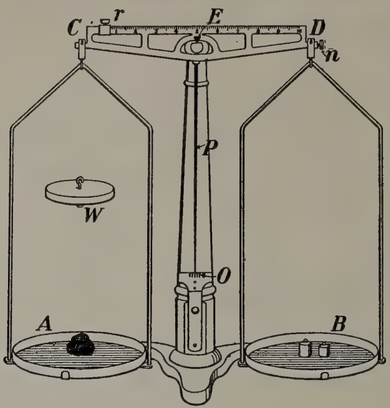


FIG. 10.—A convenient balance. Handle it with great care.

1. Keep the balance dry and free from dust.

2. See that the balance is properly adjusted, so that it will, when unloaded, either rest in equilibrium with the pointer at the zero mark on the scale, or will swing equally on either side of zero.

3. Place the body whose mass is to be ascertained in the left-hand scale-pan, and place the weights in the right-hand scale-pan. Until some experience in judging the mass of a body has been obtained, try all the weights in order, commencing with the largest and omitting none. When any weight causes the right-hand pan to descend, remove it. Never select weights at random.

In the balance shown in the figure any addition under 10 grams is obtained by sliding the rider r along the beam. It gives $\frac{1}{10}$ gram directly, and $\frac{1}{10}$ of this may be obtained by estimation.

Before beginning, the balance should be tested. Push the rider r over to its zero mark and then if the pans do not balance (as indicated by the pointer P) turn the nut n until they do.

4. To determine the equilibrium do not wait until the balance comes to rest. When it swings equally on either side of zero the mass in one pan equals that in the other.

5. Place the largest weight in the centre of the pan, and the others in the order of their denominations.

6. Keep the pans supported when weights are to be added or taken off.

7. Small weights should not be handled with the fingers. Use forceps.

8. Weigh in appropriate vessels substances liable to injure the pans. For counterpoise use shot and paper.

9. Never use the balance in a current of air.

Experiment 8.—To find the density of water.

APPARATUS:—Beaker or can of about 500 c.c. capacity, graduate, balance.

Method.—Weigh the beaker carefully and record the weight. Fill the graduate to the 100 c.c. mark, taking your reading opposite the *level* surface of the water. (It will be higher than this at the edges.) Pour the water into the beaker and weigh again. Subtract the first reading to obtain the weight of the water. Calculate the weight of 1 c.c. of water to the nearest third place of decimals.

Repeat, using 200, 300, 400 c.c. of water and tabulate the results as follows:—

VOLUME OF WATER	MASS	MASS OF 1 C.C.
100 c.c.	...... gm.	...... gm.
200 '	...... "	...... "
300 "	...... "	...... "
400 "	...... "	...... "
	AVERAGE	...... "

How does your result compare with the value given in TEXT-BOOK, § 15?

Experiment 9.—To find the volume of a rectangular solid; also its density. (TEXT-BOOK, § 15.)

APPARATUS:—Block of wood, metric rule, balance.

Method.—Apply the rule to each *edge* of the block, thus measuring each dimension of the block four times. Take the average, and by multiplying the three dimensions obtain the volume.

Weigh the block and calculate the number of grams in 1 c.c. of it. Arrange your results in a table.

Experiment 10.—To find the specific gravity of an irregular solid.

Apparatus:—Balance, piece of granite or any other solid, overflow can, catch-bucket.

Method.—Weigh the granite and the catch-bucket carefully and record their weights. Then fill the overflow can, observing the instructions given in Experiment 5, and lower the granite into it carefully, catching the overflow in the bucket. Weigh the bucket and water and subtract the weight of the bucket to find the weight of the water. Repeat the displacement at least three times, if time permits, and average your results.

Tabulate your results as follows:—

Wt. of Granite	Wt. of Bucket	Wt. of Bucket & Water	Wt. of Water
...... gm.	...... gm.	...... gm.	...... gm.
...... "	...... "	...... "	...... "
...... "	...... "	...... "	...... "
		Average	..... "

$$\text{Sp. Gr.} = \frac{\text{Weight of granite}}{\text{Weight of equal vol. water}} = \frac{\text{......} \ \text{gm.}}{\text{......} \ \text{gm.}} = \text{......}$$

Experiment 11.—To find the specific gravity of a liquid by means of the specific gravity bottle. (Text-Book, § 93.)

Apparatus:—Concentrated solution of copper sulphate or of common salt, gasoline, specific gravity bottle (Fig. 11), balance, ordinary hydrometer.

Method.—First weigh the bottle empty and dry. Then fill with water. There is a small hole in the stopper through which any excess of water escapes. Carefully wipe off the water and weigh again. Empty the water, removing it all, fill with the salt solution and weigh again.

Fig. 11.—A specific gravity bottle.

Rinse out the bottle with water, dry it as carefully as possible, fill it with gasoline and weigh once more.

Arrange your results as follows:—

Weight of bottle empty	gm.
Weight of bottle filled with water	"
Weight of bottle filled with salt solution....	"
Weight of bottle filled with gasoline........	"
Weight of water	"
Weight of salt solution....................	"
Weight of gasoline	"

$$\text{S. G. of salt solution} = \frac{\text{Weight of salt solution}}{\text{Weight of water}} = \cdots\cdots$$

$$\text{S. G. of gasoline} = \frac{\text{Weight of gasoline}}{\text{Weight of water}} = \cdots\cdots$$

Find the specific gravity of the liquids with a hydrometer and compare results.

***Experiment 12.—To find the value of 1 ounce in grams, 1 kilogram in pounds, 1 quart in c.c. and in litres.** (TEXT-BOOK, § 11.)

APPARATUS:—Balance, with both British and metric weights, quart measure, glass vessel graduated in c.c.

Method.—(*a*) Place an ounce weight on the left-hand pan of the balance (Fig. 10) and place metric weights on the right-hand pan to balance it.

(*b*) Next place the kilogram weight on the left pan, and, keeping the rider at the zero point, add British weights on the right until they balance the kilogram. Express your result in pounds and decimals.

(*c*) Carefully pour water from the graduated vessel into the quart measure until it is just filled. Then add up the amount poured in. Or, fill the quart measure and empty the water into the graduate. Express the quart in c.c. and also in litres. (1 l. = 1000 c.c.)

****Experiment 13.—To study the construction and use of the vernier calliper.**

APPARATUS:—Slide calliper, objects such as ball bearings, cylinders, glass plates, etc., whose dimensions are required.

A form of the vernier calliper is shown in Fig. 12. The scale V on the sliding jaw is the vernier and its object is to measure fractions of a division of the scale S. Usually n divisions on the vernier are equal to $n - 1$ divisions on the scale. Suppose 10 vernier divisions are equal to 9 scale divisions, and that the latter are millimetres. Then 1 division on the vernier is clearly 0.9 mm., and the difference between one scale division and one vernier division is 0.1 mm. In order to explain the action of the vernier, consider the enlarged image of the scale and vernier (Fig. 13). The object to be measured is placed between the jaws of the calliper. Suppose the zero on the vernier occupies the position shown in the figure. It is clear that the length AB is equal to 16 mm. + a fraction of a millimetre. To find this fraction, look along the vernier and see where a line on it coincides with a line on the scale. It is seen that division 7 on the vernier coincides with the line c on the scale. Then the fraction to be measured, namely the distance aB, is equal to the difference between the 7 divisions of the scale in the space ac and the seven divisions of the vernier in the space BC. But the difference between one scale division and one vernier division is 0.1 mm. Hence the fractional part is 7×0.1 or 0.7 mm., and the entire space AB is therefore 16.7 mm. or 1.67 cm.

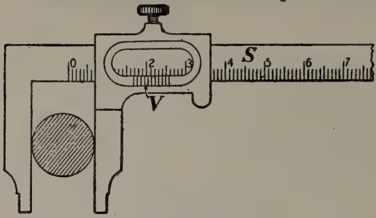


FIG. 12.—Vernier calliper.

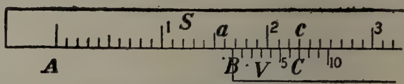


FIG. 13.—Scale and vernier.

For any other vernier the method of calculation is similar.

Method.—Place the object to be measured between the jaws of the calliper and adjust the sliding jaw until a light contact is obtained. Read the whole number of divisions which precede zero on the vernier. Then look for a division on the vernier which coincides with a scale division and add the corresponding decimal to the whole number already found.

As a general rule, the average of several readings should be taken.

****Experiment 14.—To measure the diameters of several wires and identify the number on the gauge which expresses their diameters.**

APPARATUS:—Samples of wire of different diameters, micrometer gauge.

The micrometer gauge (Fig. 14) is very convenient for measuring the diameters of wires. A is the end of an accurately made screw which

works in a nut inside D, and can be moved back and forth by turning the cap C to which it is attached and which slips over D. Upon D is a scale, which counts the number of revolutions of C, while the bevelled end of C is divided into a number of equal parts by which the fractions of a revolution are measured. By turning the cap the end A moves forward until it reaches the stop B, at which time the graduations on D and C should both read zero.

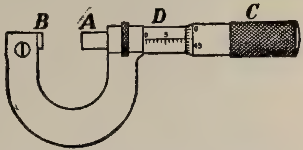


FIG. 14.—Micrometer wire gauge.

In order to measure the diameter of a wire, turn the cap C until the wire just slips between A and B. Then by reading the graduations on D and C we find how far the end A has been drawn back from B, which is the thickness of the wire.

Suppose the pitch of the screw to be $\frac{1}{2}$ mm. Then when C revolves once, the end A moves through $\frac{1}{2}$ mm. Now if on C there are 50 divisions, it is evident that when it turns through one division the end A moves through $\frac{1}{50} \times \frac{1}{2} = \frac{1}{100}$ mm. Such an instrument will measure to $\frac{1}{100}$ mm.

Sometimes the pitch of the screw is $\frac{1}{40}$ inch and there are 25 divisions on the head C, in which case one division $= \frac{1}{25} \times \frac{1}{40} = \frac{1}{1000}$ inch.

When making a measurement hold the cap C lightly and turn the screw until the wire is just grasped between A and B. The instrument must not be screwed up tight, as that would destroy the accuracy of the screw, and moreover the wire would be somewhat flattened.

Method.—Measure each wire at five different places, and take the average. Then compare your results with the sizes given in the following table and see to what number on this gauge the wires correspond:—

BROWN AND SHARPE (AMERICAN) GAUGE

No. of Wire	1	2	3	4	5	6	7	8	9	10
Diam. in mm..	7.35	6.54	5.83	5.19	4.62	4.12	3.66	3.26	2.91	2.59
No. of Wire....	11	12	13	14	15	16	17	18	19	20
Diam. in mm..	2.30	2.05	1.83	1.63	1.45	1.29	1.15	1.02	.91	.81
No. of Wire....	21	22	23	24	25	26	27	28	29	30
Diam. in mm..	.72	.64	.57	.51	.45	.40	.36	.32	.29	.25

Part II.—Mechanics of Solids

****Experiment 15.—To find the relation between the force employed to stretch a coil-spring and the amount of the stretch produced: to test a spring-balance.**

Apparatus:—A coil-spring, weights, curve paper, spring-balance graduated in ounces or grams.

A suitable spring may be made by winding spring brass wire (No. 18 or 20) on a round rod about 1 cm. in diameter, the spring thus formed being 8 or 10 cm. long. A simple form of apparatus is shown in Fig. 15. The string attached to the lower end of the spring hangs parallel to and near the edge of a graduated scale S. In the string is a knot A which serves as an index.

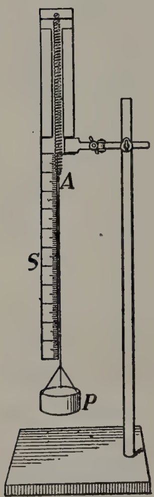


Fig. 15.—Find the relation between the load on the spring and the stretch produced.

Method.—First remove the scale-pan P, place it on an ordinary balance (see Fig. 10) and add small shot or tacks until it weighs 10 grams. Replace it and observe the position of the index A, which is the reading when the spring is stretched by a force of 10 grams. Add 10 grams and read the index again. Continue adding weights and reading the scale for each weight.

Arrange your results in a table, giving in the 1st column the stretching force, in the 2nd the reading on the scale, in the 3rd the amount of the stretch, and in the 4th the values obtained on dividing the stretching force by the amount of stretch produced by it.

Next plot your results on a sheet of curve paper (Fig. 16). Represent the different stretching forces by lengths along OX and the corresponding amounts of stretch by distances along OY.

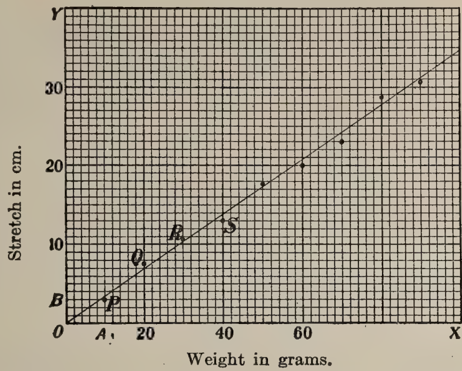


FIG. 16.—Representing results by means of a graph.

What relation exists between the stretching force and the amount of stretch produced by it?

In order to test the spring-balance hang on its hook the little pan and its load (10 grams in all). Then continually add weights to the pan, noting in each case the reading on the scale of the balance. Enter in two columns the load on the pan and the corresponding reading on the balance, and thus determine what corrections, if any, should be made to the latter. If the balance reads in pounds or ounces the British weights should be used.

Experiment 16.—To study the lever. (TEXT-BOOK, §§ 39, 67-69.)

APPARATUS:—Metre rod, hardwood prism or adjustable knife-edge to serve as a fulcrum, set of weights, spring-balance.

Method.—Lever of Class I. Place the fulcrum at the 50 cm. mark on the rod (Figs. 17, 18). If the rod does not balance, add bits of lead or plasticine to the

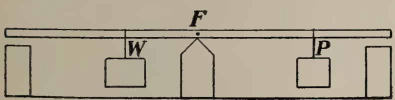


FIG. 17.—A lever of the first class.

lighter end until it does. Put blocks under the ends to reduce the vibration.

Suspend a weight P by a loop of thread placed at some graduation, noting its distance from F. This distance is called the arm of the lever, and the product $P \times FP$ is called the moment of P about F. Move the weight W until it just balances P, and note the length FW.

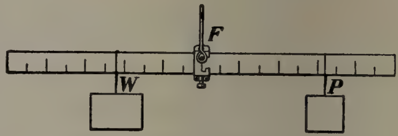


Fig. 18—A lever of the first class.

Make 5 or 6 experiments, changing the weights and arms, and tabulate the results as follows:—

P	Arm of P FP	Moment of P $P \times FP$	W	Arm of W FW	Moment of W $W \times FW$

Lever of Class II. Balance the rod and arrange the weight W as before, making the arm of W short enough to allow a spring-balance to be attached on the side of W remote from the fulcrum (Fig. 19). Note the distances of the weight and the spring-balance from F and observe the reading of the balance, when the

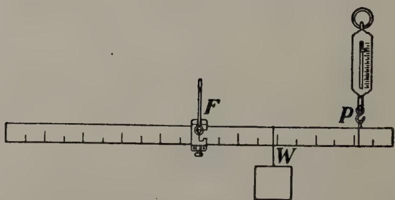


Fig. 19.—A lever of the second class.

rod is horizontal. Take at least five different readings, varying W and FW and arrange the results in the table:—

P	Arm of P FP	Moment of P $P \times FP$	W	Arm of W FW	Moment of W $W \times FW$

Lever of Class III. For a lever of the third class place a loop of fine wire or thread around the metre rod at its centre of gravity F (Fig. 20), and fasten the loop to the table. Then attach P and W so that P is between W and F, as shown.

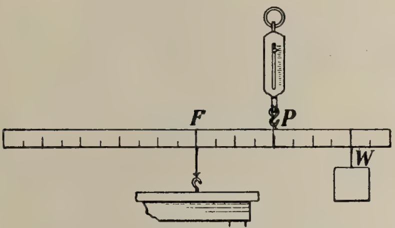


Fig. 20.—A lever of the third class.

Arrange the results in a table as in the other cases.

State the Law of the Lever.

****Experiment 17.—To find the centre of gravity and the weight of a graduated rod.** (Text-Book, §§ 57-59.)

Apparatus:—Graduated rod, prism and a weight.

Method.—Lay the rod on the edge of the prism (Fig. 21) and observe the graduation C where it balances. The centre of gravity is at this place. Next rest the rod on the prism at another place in its length, and move a weight W along it until it

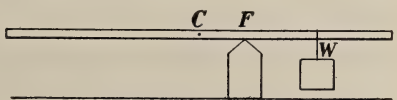


Fig. 21.—Finding the centre of gravity of a rod and its weight.

balances again. If w is the weight of the rod, we have

$$w \times CF = W \times WF,$$

from which w can be found.

Vary the weight W and the distance WF and obtain at least five results. Tabulate them and take the average of the values of w.

***Experiment 18.—To investigate the law of the lever when the forces are not perpendicular to its length.** (TEXT-BOOK, §§ 40, 41.)

APPARATUS:—Metre rod with holes drilled through it, pulleys and weights (or spring-balances).

Method.—Drive a pin (a wire nail with its head removed) in a board on the table; over this lay a sheet of paper; on the pin thread a large bead and also the metre rod, so that the pin passes through the centre hole. The bead will keep the rod from the table and will allow it to turn freely in a horizontal plane.

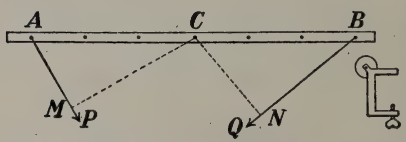


FIG. 22.—A lever with forces not perpendicular to its length.

Attach strings to any points A, B (Fig. 22) of the rod, and let these pass over pulleys at the edge of the table, with weights P and Q on the ends of the strings.

Mark on the paper the directions AM, BN of the strings and draw CM, CN, the perpendiculars from C upon these lines. Carefully measure the lengths of CM, CN. The moment of P about C is $P \times CM$; that of Q is $Q \times CN$.

Take different values of P and Q, and tabulate results as before. Then state your conclusion.

In place of weights over pulleys, spring-balances may be used.

****Experiment 19.—To find the resultant of parallel forces.** (TEXT-BOOK, § 42.)

APPARATUS:—Metre rod, spring-balances, weight.

Method.—Weigh the metre rod and find C, its centre of gravity. Attach spring-balances by loops of thread placed at A and B (Fig. 23). Suspend a weight W from the rod by a thread tied at C.

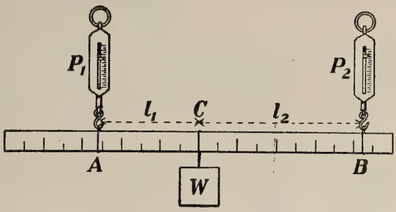


FIG. 23.—Finding the resultant of parallel forces.

See that the rod is horizontal and take the readings P_1, P_2 on the balances; measure also the distances l_1 and l_2 of the weight from P_1 and P_2. Repeat for different positions of A and B.

Since W is suspended from the centre of gravity of the rod, it is evident that we can consider the total weight at C as being $W + w$ where w is the weight of the rod.

Tabulate the results as follows:—

P_1	P_2	$P_1 + P_2$	$W + w$	$P_1 \times l_1$	$P_2 \times l_2$

Also compare $P_2 \times (l_1 + l_2)$ with $(W + w) \times l_1$, *i.e.*, take moments about A; and $P_1 \times (l_1 + l_2)$ with $(W + w) \times l_2$, *i.e.*, take moments about B.

State your conclusions.

***Experiment 20.—To find the resultant of two forces acting at a point (Parallelogram of Forces).** (TEXT-BOOK, § 44.)

APPARATUS:—Spring-balances, small ring, cord.

Method.—Fasten three cords (fish-line) to a small ring, and hook spring-balances on the other ends of the cords (Fig. 24).

By means of pins in the top of the table, over which the rings of the balances may be placed, or in any other convenient way, exert force on the balances so that the cords are under considerable tension. The balances should move free of the table top.

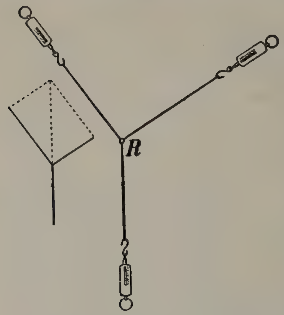


FIG. 24.—Diagram illustrating the parallelogram of forces.

Pin a sheet of paper under the strings and mark a dot precisely at R, the centre of the ring; also make dots exactly under each string and as far from R as possible.

Read each balance. Then loosen them, and when they are lying on the table observe if the index returns to zero. If it does not, a correction to the reading on the balance must be made.

With great care draw lines from R through the points under the cords, and on these lines take distances proportional to the tensions of the corresponding strings. Thus if the tensions be 1000, 1500, 2000 grams, take lengths 10, 15, 20 cm. or 4, 6, 8 inches.

Using any two of these lines as adjacent sides, complete a parallelogram, taking care to have the opposite sides accurately parallel. Draw the diagonal between these adjacent sides and carefully measure its length. Compare it as to length and direction with the third line.

State your conclusion.

***Experiment 21.—To study the action of pulleys.** (TEXT-BOOK, §§ 70-72.)

APPARATUS:—Systems of pulleys as in Figs. 25, 26, 27. The pulleys should work with very little friction. Aluminium pulleys are recommended.

Method.—Place a weight W on one pan (Fig. 25), and on the other pan add weights P until W just begins to move upward. If there were no friction P and W would be equal. The friction $= P - W$.

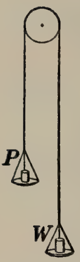


FIG. 25.—Find the relation between P and W.

Take 8 or 10 different values of W and determine the P in each case which will just cause W to rise. Arrange the results in a table with headings P, W, $P - W$. Also draw a curve, having the values of P for ordinates and the corresponding values of W for abscissas.

What do you conclude as to the ratio between P and W?

Make similar experiments with the arrangements shown in Figs. 26, 27. In these cases find the ratio between the distances moved through by P and W; also find, for different values of P and W, the value of the ratio W/P = mechanical advantage.

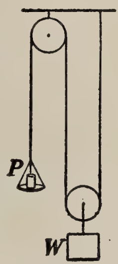


FIG. 26.

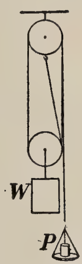


FIG. 27

***Experiment 22.—To illustrate the principle of work by the inclined plane.** (TEXT-BOOK, §§ 49, 51, 76.)

APPARATUS:—As in Fig 28.

Method.—Set the inclined plane at an angle of 45°. The carriage W and the pulley should move with very little friction. Unless this is the case the experiment will not be satisfactory. Place a weight on W, and then add to P until W just moves up the plane. This can be done by attaching a pail to the string and using sand, water or shot to increase the weight. Let P_1 be the weight in this case. Then lighten P until W just moves down the

plane; let P_2 be the weight now. Take $\frac{1}{2}(P_1 + P_2) = P$ as the weight required to balance W if there were no friction.

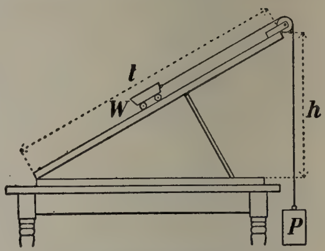


FIG. 28.—Show that $Pl = Wh$.

It is evident that when W passes from one end of the plane to the other it rises through a distance h, the height of the plane, and hence the work done is Wh; while P passes through a distance l, the length of the plane, and so does work Pl. Hence $Pl = Wh$, or $P = W\frac{h}{l}$.

Measure the distances h and l with a metre rod.

Use different values of W and different inclinations of the plane, and tabulate the results thus:—

P_1	P_2	$P = \frac{1}{2}(P_1+P_2)$	l	Pl	W	h	Wh

What conclusion can be drawn from this experiment?

****Experiment 23.—To investigate the laws of the pendulum.**

APPARATUS:—Pendulum consisting of a metal sphere suspended by a fine thread from a clamp as in Fig. 29 (or in any other convenient way), watch.

The length of the pendulum is the distance from the lower face of the block to the centre of the bob. The motion of the pendulum from its extreme position on either side back to that position again (*i.e.*, a "double-swing") is called an *oscillation*, and the time taken to make an oscillation is called its *period*. The *amplitude* of the oscillation is the distance from its middle, or lowest, point to its extreme position.

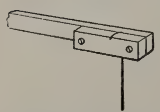


FIG. 29.—One way to suspend a pendulum.

Method.—First, test whether a difference in the amplitude of the oscillation produces a change in the period. Use a

pendulum 150 cm. long, or even longer, and have as heavy a bob as possible. Find, in seconds, the time it takes the pendulum to make twenty oscillations and deduce the period. (It is well for one student to observe the second hand of the watch while another counts the oscillations.) To determine the time with greater accuracy, a stop-watch may be used if available. Start with various amplitudes, such as 10, 20, 40, 60, 100 cm., and tabulate the results as follows:—

Trial	No. of Oscillations	Time	Period	Amplitude	
				At Start	At End
1	....	....	....	....	....
2	....	....	....	....	....
3	....	....	....	....	....

What is the effect of a large amplitude?

Second, find the relation between the length of the pendulum and its period. Take pendulums with lengths 150, 120, 100, 80, 60, 25, 10 cm. and find the period for each. For the shorter ones take the time for forty or fifty oscillations. Arrange the results in a table as below:—

Trial	Length of Pendulum l	Period T	$\frac{l}{T^2}$
1	.... cm.	.... sec.	....
2	.... "	.... "	....
3	.... "	.... "	....

Now plot two curves. In one have length of pendulum as ordinate and period as abscissa. In the other use length of pendulum as ordinate and square of period as abscissa.

Deduce from your curves the length of a pendulum whose period is 1 sec., 2 sec.

State the laws of the pendulum.

It can be shown that if g = acceleration due to gravity, l = length of pendulum and T = its period, then $g = 4\pi^2\frac{l}{T^2}$. From the last column in the second table above deduce the values of g.

***Experiment 24.—To study motion with uniform acceleration.** (TEXT-BOOK, §§ 21, 22.)

APPARATUS:—That shown in Fig. 30. It consists of a board 5 or 6 ft. long with an accurately made cylindrical groove (radius = 4 in.). The

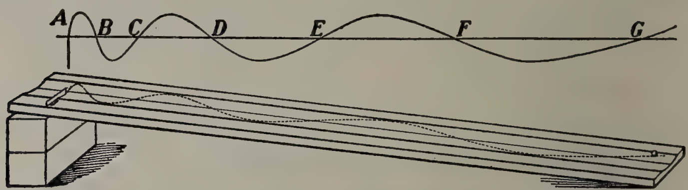


FIG. 30.—Apparatus for studying uniformly accelerated motion.

surface should be painted black and polished smooth. Near one end a metal strip at right angles to the length of the board projects out to the middle of the groove. A steel or brass sphere, 1 to 1½ inches in diameter is required.

Method.—First lay the board on the floor or on a table, and let the sphere oscillate across the groove. Count the time for a large number of oscillations and deduce the period of a single one.

Now scatter lycopodium powder on the groove. This can be done through 4 or 5 thicknesses of muslin. Then raise one end of the board about 8 in., and, placing the sphere at one side of the groove and next the metal strip, let it go. It oscillates across the groove and at the same time runs down the board, and the metal strip causes it to start with no velocity down the groove.

Blow off the powder, and there will be left a curve like that in the figure. With a metre rod measure the distances AB,

AC, AD, ... along the middle of the groove. If $2t$ is the time of an oscillation, the times required to travel these distances are t, $2t$, $3t$, $4t$, ... Tabulate your observations as follows:—

DISTANCE	TIME	$\frac{\text{DISTANCE}}{(\text{TIME})^2}$
...... cm.	...... sec.	......
...... "	...... "	......
...... "	...... "	......
...... "	...... "	......

The numbers in the last column are equal to $\frac{1}{2}a$, where a = acceleration. ($s = \frac{1}{2}at^2$, TEXT-BOOK, § 21.)

Find the acceleration, with at least two inclinations.

Draw a curve having distance travelled as ordinates and the squares of the times required to travel the corresponding spaces as abscissas.

***Experiment 25.—To find the acceleration due to gravity.** (TEXT-BOOK, § 23.)

APPARATUS:—The apparatus is shown in Fig. 31. P is a straight wooden rod about 4 ft. long, $1\frac{1}{4}$in. wide and $\frac{1}{2}$ in. thick, pivoted on a pin p in a board B fastened to the wall. (A piece of metal tubing can be inserted in the rod to rest on a knife-edge made by filing a nail driven in the board). A metal ball b is attached to a thread, which passes over the smooth-running pulley C. S is another "frictionless" pulley.

Method.—Let the rod hang vertically, and see that the ball hangs just clear of the rod at the top. C should be mounted to allow for this. Then lower the ball and find if it hangs just free of the rod near the bottom. By turning the small piece of wood d, this latter adjustment can be made.

Cover about 20 cm. of the right-hand face of the rod with white paper and by means of rubber bands fasten carbon paper over this with the ink face inwards. Then pass the thread over S and tie it to a screw-eye in the rod so that the ball is opposite the line on B and the rod is pulled aside as in the diagram.

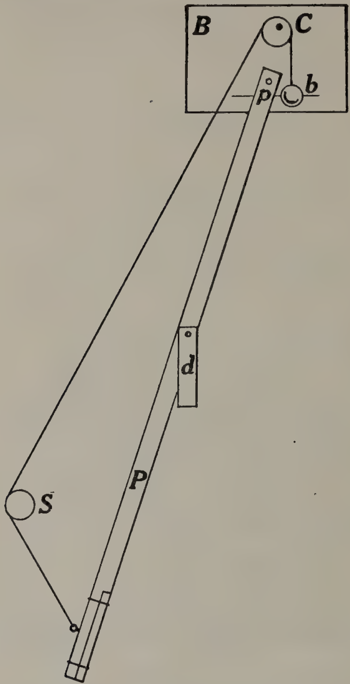


FIG. 31.—Determination of 'g'.

Burn the thread near C, thus releasing b and P at the same time. As the pendulum passes through the vertical position it strikes the ball and a mark is made on the white paper. Measure the distance S from the top of this mark to the line drawn on B.

Next pull the rod aside and let it swing. Take the time for twenty complete swings and calculate the period.

Then $s = \frac{1}{2} gt^2$, where t is one-quarter of the period of the pendulum.

Repeat the experiment at least three times and find the average value of g.

****Experiment 26.—To find the coefficient of friction between pine and pine.** (TEXT-BOOK, §§ 62-64.)

APPARATUS:—As shown in Fig. 32. The apparatus used in Experiment 22 may be employed for this purpose.

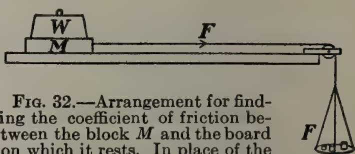


FIG. 32.—Arrangement for finding the coefficient of friction between the block M and the board on which it rests. In place of the weight over a pulley a spring-balance may be used.

Method.—Weigh the block M; let it be w. Rub it to and fro vigorously on the

supporting board. Then place a weight W on it. Place a small weight in the scale-pan and add others in succession until uniform motion takes place. Gently tap the board each time a weight is added to the scale-pan. Note the total force F producing the motion. Then

$$\text{Coefficient of friction} = \frac{F}{W + w}.$$

Try various weights and make many experiments. Having obtained a value of the coefficient for each weight tried, draw a curve using the values of the total weight $W + w$ as ordinates, and those of F, the force exerted, as abscissas.

Arrange the results in a table, having as headings of the columns, $W + w$, F and $\frac{F}{W+w}$.

****Experiment 27.—To find the horse-power developed by a water motor and to test its efficiency.** (TEXT-BOOK, § 56.)

APPARATUS:—Small water motor, two spring-balances (0-2000 gm.), piece of cord or sewing-machine belt to act as brake, supports for balances, pressure gauge, large vessel to catch water, revolution counter.

Method.—Arrange the apparatus as in Fig. 33. Adjust the balances to read about 300 gm. Turn on the water and note the reading of the gauge and of the two spring-balances. Note also the number of revolutions the motor makes in 30 sec., and from this calculate the number of revolutions per second. Measure the circumference of the pulley and also the number of c.c. of water which pass through the motor in a given time (say five minutes).

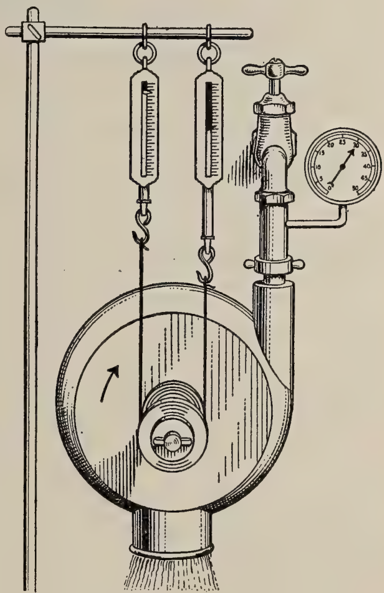


FIG. 33.—Testing the horse-power of a water motor.

Calculate the horse-power developed and the efficiency as in the following numerical example:—

Horse-power

Reading of 1st balance......550 gm.
Reading of 2nd balance......50 gm.
Force of friction............500 gm.
Revolutions per second...... 25
Circumference of pulley......20 cm.

Work done per second $= F \times S$

$$= \frac{500 \times 980 \times 20 \times 25}{10^7} = 24.5 \text{ joules.}$$

$$\therefore \text{ Power } = 24.5 \text{ watts } = \frac{24.5}{746} = \frac{1}{30} \text{ h.p. (approx.)}$$

Efficiency

Output = 24.5 joules per sec.

Input.

Reading of gauge......2000 gm. per sq. cm.
Volume of water per sec............400 c.c.

Energy supplied by water $= P \times V$

$$= \frac{2000 \times 980 \times 400}{10^7} = 78.4 \text{ joules per sec.}$$

$$\therefore \text{ Efficiency } = \frac{24.5}{78.4} \times 100\% = 31.2\%$$

Find the h.p. and the efficiency of the motor when under different loads. Note the speed at which it develops its maximum horse-power.

Part III.—Mechanics of Fluids and Surface Tension

***Experiment 28.—To prove that in a liquid at rest under gravity the pressure exerted is proportional to the depth, is the same in all directions and is independent of the mass of liquid used.** (Text-Book, §§ 84, 85.)

Apparatus:—The pressure gauge consists of a small glass funnel (or *thistle-tube*) *A* (Fig. 34), over which is tied thin sheet rubber, such as dentists use. A rubber tube *D* connects the funnel to a **U**-shaped glass tube *F*, of small bore, in which is coloured water or aniline oil which acts as a manometer (or pressure measurer). An increase of pressure on the sheet rubber forces it inwards and this will cause a difference in the levels of the liquid in the manometer, the amount of which can be measured. The thistle-tube is fastened to the lower end of a metre stick in such a way that it can turn about a horizontal axis in the plane of the rubber. In this way the rubber sheet may be made to face any direction.

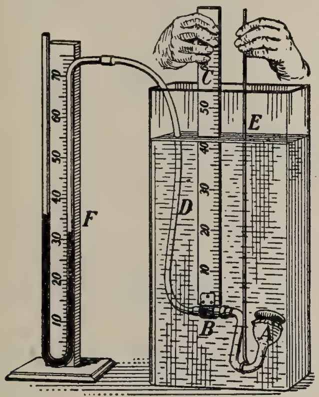


Fig. 34.—Apparatus to show that pressure is proportional to depth and is the same in all directions.

Method.—Lower the funnel into the water (which should be at the same temperature as the room) until 10 cm. below the surface. Note the depth and observe the difference in the levels of the liquid in the manometer. By means of a wire attached to the funnel turn it so that it faces in different directions, and observe any change in the manometer. Be careful not to kink the tube.

Lower the funnel 10 cm. further; note the depth and the difference in the levels. Rotate as before and observe the manometer reading. Continue this until the bottom of the vessel is reached.

Next, use a vessel of smaller cross-section and repeat the operations.

Tabulate the results in each case. Draw a curve in which ordinates represent depths of the rubber sheet and abscissas represent differences in the levels in the manometer.

What general laws do you infer regarding the pressure exerted by a liquid?

Experiment 29.—To find the loss of weight of a solid when immersed in a liquid. (Illustration of Archimedes' Principle.) (Text-Book, § 89.)

Apparatus:—Balance, overflow can, catch-bucket or beaker, piece of stone or iron.

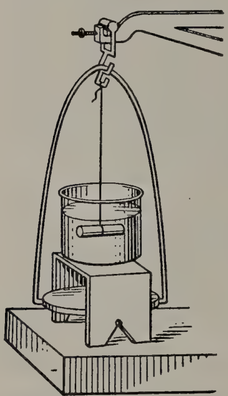


Fig. 35.—Finding the apparent loss in weight when a body is immersed in a liquid.

Method.—By means of a fine thread suspend the stone or iron from one end of the balance, and find its weight. Then surround the body with water, as in Fig. 35, and weigh again. Subtract these two weights to find the buoyant force.

Next, lower the body into an overflow can (Fig. 7, page 11), and catch the overflow in the bucket or beaker whose weight has been carefully determined. Weigh again, and by subtraction find the weight of the water displaced by the body.

Compare the buoyant force with the weight of the water displaced.

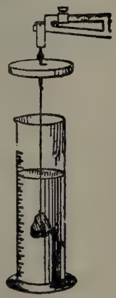


Fig. 36.—Determination of volume of liquid displaced by a solid.

Instead of the overflow vessel a graduated tube (Fig. 36) may be used to determine the weight of the displaced water. The volume of the water displaced is read from the graduations, and the mass determined by multiplying this volume by the density of water.

If time permits, repeat the experiment, using gasoline or salt solution instead of water.

State your conclusion in general terms.

Experiment 30.—By means of the balance to find the specific gravity of a heavy body. (TEXT-BOOK, § 91.)

APPARATUS:—Balance used in Experiment 29; a piece of iron, aluminium or glass.

Method.—Suspend the body from an arm of the balance and weigh it in air. Then weigh it when immersed in water. Find the loss in weight. This is equal to the weight of a volume of water equal to the volume of the body.

$$\text{Then specific gravity} = \frac{\text{weight in air}}{\text{loss of weight in water}}.$$

Be careful to remove air-bubbles. What effect will they have?

If the temperature of the water rises, what will be the effect on the result you obtain?

Experiment 31.—To find the specific gravity of a body which will float in water. (TEXT-BOOK, § 92.)

APPARATUS:—Balance, overflow can, graduate, block of wood or of paraffin wax, piece of lead to act as sinker.

Method I.—Weigh the wood. Then by means of a pin press the wood down into the water in an overflow vessel until it is entirely submerged. Catch the water and weigh it. This is the weight of the water displaced by the wood, which, divided into the weight of the wood in air, gives the specific gravity.

Method II.—Instead of using the balance, place a graduate under the spout of the overflow vessel. Carefully lay the wood on the water in the vessel and observe the overflow into the graduate. Suppose it is x c.c.; its weight and also the weight of the wood is x grams. (Principle of Flotation)

Now press the wood down until entirely submerged, catching the water as before. Suppose the water displaced is y c.c., which weighs y grams.

Then the specific gravity $= x \div y$.

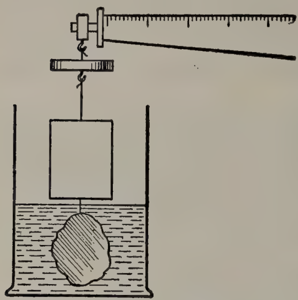


FIG. 37.—Using a sinker to find the specific gravity of wood.

Method III.—1st. Weigh the body in air. Let this be m grams.

2nd. Attach a sinker and weigh both, *with the sinker only in water*, (Fig. 37.) Let this be m_1 grams.

3rd. Weigh both, *with both in water*. Let this be m_2 grams.

Now the only difference between the second and third operations is that in the former case the body is weighed in air, in the latter in water. The sinker is in the water in both cases.

Hence $m_1 - m_2 =$ buoyancy of the water on the body, and the specific gravity $= \dfrac{m}{m_1 - m_2}$.

Compare the results obtained by the three methods.

If a block of wood is used it should be dipped in hot paraffin. Why?

Experiment 32.—To find the specific gravity of a liquid by weighing a solid first in water and then in the liquid. (TEXT-BOOK, § 94.)

APPARATUS:—Balance, beaker, piece of glass or iron, alcohol, concentrated salt solution or gasoline.

Method.—First weigh the solid in air, then in water and then in the liquid. Let the weights be w_1, w_2, w_3, respectively. Then $w_1 - w_2 =$ weight of a volume of water equal to that of the solid, and $w_1 - w_3 =$ weight of a volume of the liquid equal to that of the solid.

$$\text{Hence the specific gravity} = \frac{w_1 - w_3}{w_1 - w_2}.$$

***Experiment 33.—To compare the densities of two liquids which do not mix (water and oil).**

APPARATUS:—Use a **U**-tube, mounted as shown in Fig. 38.

If the glass tubing is not more than ¼ or ⅜ inch in diameter it may be bent in an ordinary flat gas-flame, and in place of a bent glass tube two straight pieces can be connected by a piece of rubber tubing securely bound on.

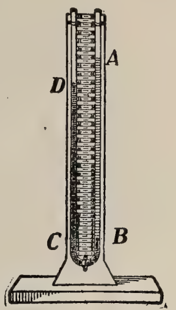


FIG. 38.—**U**-tube to compare densities of liquids.

Method.—Pour water (through a funnel) into one limb of the tube until both limbs are about one-third full. Then slowly pour in oil until the surface of separation B, between the oil and the water, is nearly down to the bend of the tube.

Let A be the free surface of the oil and D that of the water. It is evident that the height AB of oil balances the height CD of water, and so

$$AB \times \text{density of oil} = CD \times \text{density of water},$$

$$\text{or density of oil} = \frac{CD}{AB} \times \text{density of water}.$$

If the glass tubing is small some allowance should be made for capillarity. Hold pieces of the tubing in water and in oil and observe how far the liquids rise by capillary action. Measure this in millimetres and subtract from the height of the liquid. It is better to use a tube with internal diameter not less than ⅜ inch, and thus avoid any correction for capillarity.

Turpentine or mercury may be used in place of the oil, but the latter is not so satisfactory. Why?

What would be the effect of having one limb of the tube larger than the other?

***Experiment 34.—To compare, by means of balancing columns, the densities of two liquids which mix.**

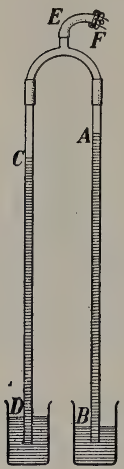


FIG. 39.-Comparison of densities by balancing columns.

APPARATUS:—Suitable liquids to compare are water and a solution of copper sulphate or of common salt. The apparatus is illustrated in Fig. 39. The upright glass tubes are joined by rubber tubing to a 3-way glass tube, and the rubber tube E can be closed by a pinch-cock F.

Method.—Fill one tumbler with water and the other with the copper sulphate (or other) solution and record the height to which each liquid rises by capillary action, the pinch-cock being open.

Apply the lips to the tube E and draw out some of the air, thus allowing the pressure of the air outside to force the liquids into the tubes. When the lighter one reaches nearly to the top of the glass tube, pinch the rubber tube and close the pinch-cock. Watch the columns to make sure that there is no falling in the surfaces through the connections not being tight. (Moisten the connections occasionally with a little glycerine to keep them air-tight.) When sure that the columns are steady, measure the heights AB, CD of the surfaces of the liquid columns above the liquid in the tumblers, and deduct from these the heights to which the liquids rose by capillary action.

Let water be in the right tube and copper sulphate solution in the left.

$$\text{Then } CD \times \text{density of solution} = AB \times \text{density of water,}$$

$$\text{or density of solution} = \frac{AB}{CD} \times \text{density of water.}$$

Experiment 35.—To find the weight of a litre of air. (Text-Book, § 96.)

Apparatus:—A burned-out sixty-watt electric light bulb, balance, sharp three-cornered file, overflow can and graduate.

Method.—Weigh the bulb carefully to the second decimal place in grams. (Weigh to the third place if the balance is sensitive enough.) Then, using the file, with a firm pressure cut a hole in the bulb near the brass base, (Fig. 40). Make sure that no glass has been lost and weigh again carefully. Subtract the weights, and thus find the weight of the air which has rushed into the bulb.

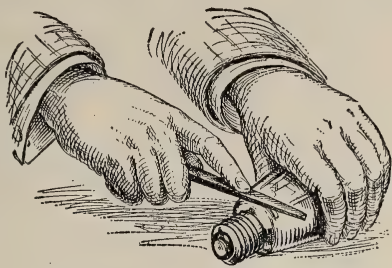


Fig. 40.—Filing bulb to allow air to enter.

Next, immerse the bulb as far as the brass base in the overflow can and catch in the graduate the water which is displaced. Read the volume in c.c. This will be very nearly the volume of the air in the bulb.

Calculate the weight of one litre of air.

The above method will not give very accurate results. Name some sources of error. Can you suggest a more accurate method using more complicated apparatus?

Experiment 36.—To measure the pressure of the gas in the city mains, or in a vessel into which air is pumped.

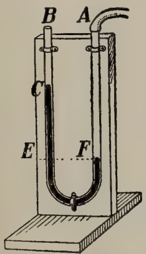


Fig. 41.—Measuring the pressure of the gas.

Apparatus:—U-tube as shown in Fig. 41.

Method.—Pour water (coloured, if desired, with a little aniline dye) into one end of the tube. It will take, of course, the same height in each arm. Measure this height above the base. What is the pressure on each surface now?

Attach one end *A* of the tube, by means of a rubber tube, to a gas-tap, and turn on the gas. The column of water in *A* will be depressed, that in *B* raised. Read the height of each column and deduce the difference in the levels.

It is evident that the pressure of the gas at F is equal to the pressure of the atmosphere + that due to a column CE of water.

Calculate this latter pressure in grams per square cm.

Would this height be changed if the diameter of the tube were increased?

If a city gas supply is not available, measure the pressure in a bottle into which air is forced by a bicycle pump attached to the rubber tube A (Figure 42) which is attached to a glass tube passing through the stopper.

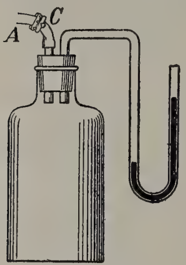


FIG. 42.—Measuring the pressure of the air in a bottle.

Find the difference in level produced by one full stroke of the pump, then by two, three, four, etc., strokes, a pinch-cock C being used to prevent the air from escaping.

Instead of glass tube and pinch-cock a bicycle tire valve may be passed through the cork.

If alcohol or mercury had been used instead of water, what would have been the difference in the levels?

***Experiment 37.—To measure the pressure exerted by the atmosphere.** (TEXT-BOOK, §§ 98, 103.)

APPARATUS:—A heavy glass tube about 80 cm. long, closed at one end (the internal diameter of the tube should be at least ¼ inch); mercury; dish.

Method.—Pour mercury into the tube until it is nearly filled. Hold the finger over the open end and invert the tube several times in order to collect the air bubbles.* Then complete the filling of the tube, hold the finger over the open end and invert the tube, placing the open end under the sur-

*The air cannot be fully eliminated without boiling the mercury in the tube, and to do this requires special apparatus.

face of mercury in a dish. Support the tube in a vertical position and measure the height of the mercury in the tube above that in the dish (Fig. 43). Let it be h cm.

Now the pressure exerted by a liquid depends only on its depth. Suppose the section of the tube to be one sq. cm. Then there would be h c.c. of mercury in the tube, and the weight of this is the pressure on 1 sq. cm.; and as this is just balanced by the pressure of the atmosphere, this is the atmospheric pressure required.

1 c.c. of mercury weighs 13.6 grams and hence the atmospheric pressure = $13.6 \times h$ grams per sq. cm.

Find the pressure in grams per sq. cm. and also calculate it in pounds per sq. in. (See table, page 153.)

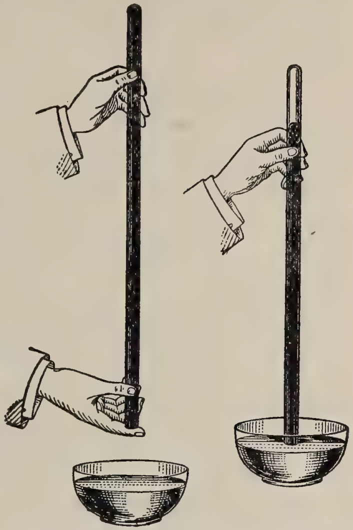


FIG. 43—Measuring the pressure of the atmosphere.

Experiment 38.—To find the way in which the volume of a given mass of gas changes when its pressure is changed, the temperature being kept constant (Boyle's Law). (TEXT-BOOK, § 110.)

APPARATUS:—Obtain a piece of glass tubing about 1 metre long with a small bore (not more than 1 mm.). By suction draw into the tube enough mercury to fill about one-third of its length, taking care not to allow any moisture to enter. Then hold the tube horizontally, with the mercury column midway between the ends and seal one end with a blow pipe or by using sealing-wax.

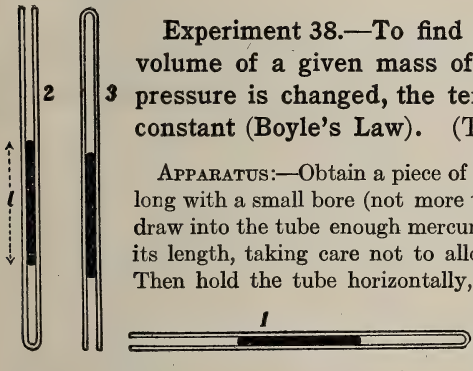


FIG. 44.—Three positions of a tube with air in it for verifying Boyle's Law.

Method.—Read the barometer carefully. Then lay the tube horizontally on the table and measure the length of the

imprisoned air and also the length of the mercury column. Repeat the readings when the tube is in a vertical position with the open end up and also when the open end is down (Fig. 44).

If p is the height of the barometer and l is the length of the mercury column in the tube, the pressure in the first case is p, in the second case $p+l$, and in the third case $p-l$. Also if the tube is of uniform cross-section the volume of the inclosed air is proportional to its length, and consequently the number representing the length can be used to represent the volume also.

Results may be tabulated as follows:

POSITION	VOLUME, V	PRESSURE, P	PRODUCT, $P \times V$
1	$V_1 =$	$p =$	
2	$V_2 =$	$p + l =$	
3	$V_3 =$	$p - l =$	

What conclusion can you draw from the experiment?

***Experiment 39.—To find the way in which the volume of a given mass of gas changes when its pressure is changed, the temperature being kept constant, that is, to verify Boyle's Law (second method).** (TEXT-BOOK, § 110.)

APPARATUS:—The apparatus is shown in Fig. 45. Two glass tubes, A and B, are supported in such a way that either may be raised or lowered. The upper end of A is closed, that of B is open, and their lower ends are joined by a heavy rubber tube securely wired to the glass. The rubber tube and part of A and B are filled with mercury. When the mercury is at the same level in both glass tubes A should be about half-full of dry air. This is most easily effected by providing the upper end of A with a stop-cock, which can be kept air-tight by the application of a little vaseline. The tube A is of uniform bore and the volume of the air may be taken proportional to the length of the tube occupied by it, this being obtained from the scale against which it is placed. When the mercury is at the same level in both tubes the air is under the pressure of one atmosphere, that is, the pressure shown by the barometer. If B is

lowered, the mercury stands higher in A than it does in B and the pressure exerted on the imprisoned air is the barometric height − the difference between the levels of the mercury in the two tubes. When the level of B is above that of A the pressure on the imprisoned air is the barometric height + the difference in level.

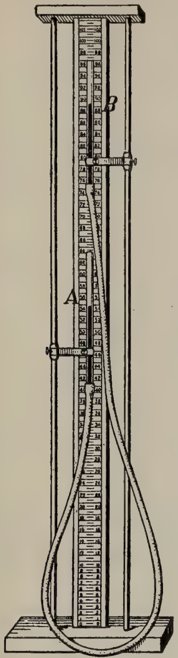


FIG. 45.—Boyle's Law apparatus. A, closed tube; B, open tube.

The tube A should not be handled for fear of raising the temperature of the inclosed air. For the same reason the air should not be compressed or expanded quickly.

Method.—Read the barometer and record its height in cm. of mercury. Note the length of the air column in A when the mercury is at the same level in both tubes.

Next, lower B slowly as far as it will go. Then take the levels of the mercury in the two tubes and calculate the pressure on the air in A. Record also the new length of the air column.

Now raise B a few cm. and take the readings again. Continue this until B is as high as it can go.

Tabulate your results as follows:—

Level of Mercury in		Differ'nce between the Levels	Height of Barometer	Total Pressure in cm. of Mercury, P	Length of Air in Tube, V	Product, $P \times V$
Closed Tube	Open Tube					

Draw a curve having the values of P for ordinates and those of V for abscissas.

State your conclusion.

****Experiment 40.—To find the surface tension of a soap solution.** (Text-Book, § 152.)

Apparatus:—Balance, fork-shaped pieces of wire with parallel prongs about 6, 8 and 10 cm. apart (*a*, Fig. 46), strong Castile soap solution with some glycerine added, beaker, rule.

Method.—Measure the distance between the prongs of the fork carefully and then suspend it from one arm of the balance. Place the beaker of soap solution under the fork so that the cross-bar of the fork is about one-half centimetre above the liquid when the beam is horizontal (Fig. 46).

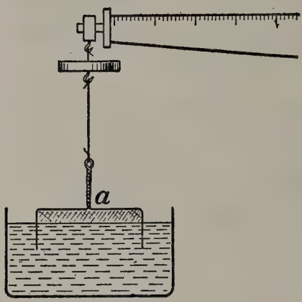


Fig. 46.—Measuring the surface tension of a soap solution.

Raise the beaker in order to wet the fork; then lower it, break the film and weigh carefully.

Repeat the operation without breaking the film and weigh again

Subtract the weights to find the pull exerted by the film. Reduce this to dynes (1 gram = 980 dynes) and divide the force in dynes by twice the distance between the prongs (because of the two surfaces of the film). This gives the surface tension in dynes per centimetre length of film.

Repeat the experiment with different sized forks and also with distilled and tap water if time permits. When using water, it is more difficult to get the film to last long enough to make the weighing, but a little patience will produce very good results.

****Experiment 41.—To compare the surface tensions of different liquids.**

APPARATUS:—Piece of fine-bore capillary tubing, beaker, rule, water, alcohol, etc.

Method.—Place the lower end of the capillary tube in distilled water in the beaker and measure the distance to which the water rises in the tube above the level of the water in the beaker (Fig. 47). In doing this apply the mouth to the upper end of the tube and draw the water up until it rises nearly to the top and then allow it to settle to its final position.

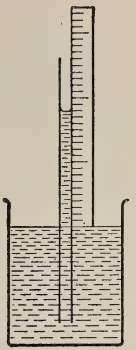


FIG. 47—Comparing the surface tensions of different liquids.

Wash the tube out well with the next liquid to be used and repeat the measurement.

Then if h_1 is the height for water and d_1 its density and h_2 is the height for the second liquid and d_2 its density,

$$\text{the surface tension of the liquid} = \frac{h_2\, d_2}{h_1\, d_1} \times \text{the surface tension of water.}$$

The surface tension of distilled water is about 81 dynes per cm. length.

Assuming this, find the surface tensions of the soap solution and tap water and alcohol.

***Experiment 42.—To study the origin of sound. (TEXT-BOOK, §§ 158, 159.)**

APPARATUS:—Strip of steel, clamp or vice, bell, pith-ball, tuning-fork, rubber stopper, whistle, cork, glass tube about 1 in. in diameter and 10 in. long.

Method.—1. Clamp a knitting-needle or a narrow strip of steel in a vice so that about 15 cm. projects. Draw the free end aside and let it go. A low, deep note is emitted, and you can *see* that the end of the needle is vibrating. Touch the tip of your finger to it; contact with the finger stops the vibration and at the same time the sound ceases. Shorten the projecting portion and examine the motion again. What difference do you observe in the nature of the vibration and of the note? Do you observe any relation between the loudness of the sound and the amplitude of the vibrations? Do you detect any relation between the length of the vibrating strip, the frequency of the vibrations and the pitch of the note?

2. Cause a bell to sound by striking it with a pencil or a bit of wood, and while it is sounding hold a pith-ball (or other light object) on the end of a thread so that it rests lightly against the rim of the bell. What result do you observe? Explore all around the rim with the pith-ball. Is the action the same at all points?

3. Sound a tuning-fork by striking it with a soft rubber stopper on the end of a stick. Touch the suspended pith-ball to different parts of the sounding fork. Touch the prongs to the surface of water. Hold the stem of the vibrating fork on a board (the top of a table). Why is the sound louder?

4. Cut off the mouth-end of a common wooden or metal whistle about midway between the first and second holes, and insert it tightly through a cork in one end of a glass tube.

Into the tube put some powder made by rubbing a baked cork on a file or on sandpaper. Then close the end of the tube. Now hold the tube in a horizontal position and blow the whistle. Describe the behaviour of the powder. What do you conclude as to the condition of the air when the whistle is sounding? How can you show that the sound does not come from vibrations of the substance composing the whistle or the tube?

***Experiment. 43—To determine the velocity of sound in air by means of a stop-watch and a gun.** (Text-Book, § 163.)

Apparatus:—Two observers are required, one provided with a gun, the other with a stop-watch.

Method.—On a quiet day let the two observers take positions about a mile apart, each in full view of the other. When ready the one with the gun waves a flag—or if at night, a lantern—to call the other's attention. He then fires the gun. Immediately on seeing the flash or the smoke the observer with the watch starts it, and on hearing the report he stops it again. The time thus recorded is the time required for the sound to travel the distance between the observers. (The time required for the light to travel this distance is neglected as it is so excessively short). If a stop-watch is not available an ordinary one may be used but it is not nearly so satisfactory. Calculate the velocity per second. For convenience the one with the watch should have a flag or a lantern too.

Make as many observations as possible and take the average. If in the country, the distance may be found from concession or side-lines; if in a town, a map of the place may be consulted.

If a breeze is blowing, the observers should interchange positions and thus obtain the velocity in each direction. The mean of these results may be taken as the velocity in still air.

Take the temperature of the air at the time, and, assuming that the velocity decreases 60 cm. or 2 ft. for a fall of 1° C., calculate the velocity at the freezing-point.

Experiment 44.—To find the wave-length of a sound and the velocity of sound in air by resonance. (TEXT-BOOK, §§ 199-201.)

APPARATUS:—Tuning-fork of known frequency, glass or brass tube about 3 cm. in diameter and 40 cm. long, tube of the same length which will just slide inside the other, tall glass jar containing water, metre stick.

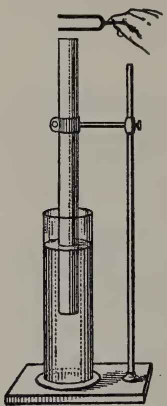


FIG. 48—Resonance apparatus for velocity of sound.

Method.—Immerse one end of either tube in the water, set the tuning-fork vibrating and hold it over the open end as shown in Fig. 48. Then move the tube up and down in the water (keeping the fork close to it) until the sound reaches its maximum intensity. The column of air in the tube is now in resonance with the fork.

Measure the length of the air-column. The length giving resonance with the fork used is approximately one-fourth of the wave-length of the sound produced by the fork. (Strictly, this length depends somewhat on the diameter of the tube. To obtain the quarter-wave-length with greater accuracy add 2/5 of the diameter of the tube to the length of the column.)

Repeat the experiment at least three times and calculate the average wave-length. Then find the velocity of sound in air by multiplying the wave-length by the frequency of the fork ($v = nl$).

If forks of other frequencies are available, compare the results obtained by using different forks. If a tall jar is not at hand, the experiment may be performed by inserting a well-fitting piston in the tube.

Next, place one tube inside the other and hold a vibrating fork near one end of the telescoping tube, while the other end is left open. Vary the length until the maximum sound is heard. Measure the length and multiply by 2 to obtain the wave-length. Compare this with the former result.

***Experiment 45.—To find the velocity of sound in glass or in metal by Kundt's Method.** (TEXT-BOOK, § 176.)

APPARATUS:—The apparatus consists of a glass tube 1 m. or more in length and 3 or 4 cm. in diameter, held on a base. It is closed at one end by a tightly-fitting piston *A*, and in the other end is a loose piston *B*, made from a thin cork cemented to the end of a long glass (or metal) rod

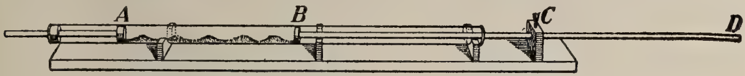


FIG. 49.—Apparatus for finding the velocity of sound in a solid.

or tube 1 cm. or less in diameter. The rod is securely clamped at its middle *C*. Soft cotton cord may be wrapped about the circumference of the cork piston in order to fit the tube snugly and still move with no appreciable friction against the wall of the tube.

Method.—Distribute evenly in the large tube a little cork-dust made by rubbing a baked cork against a file or sand-paper. Then excite longitudinal vibrations in the glass rod by gently stroking it from the centre towards the free end with a damp cotton cloth. A little practice will enable one to produce a clear high note. Be very careful not to break the rod.

Adjust the position of the piston *A* until, when the rod is rubbed, the cork-dust is violently agitated and settles into parallel ridges with uniform spaces between. Unless the adjustment is exact the end ridges will not be perfect. The dust gathers at the nodes, where the agitation is least, and the loops are half-way between. The distance between successive nodal lines is one-half the length of the sound-wave in air. Measure with a metre rod the distance between two well separated nodes, and divide by the number of node-to-node spaces in this distance. Multiply the result by 2 to find the wave-length of the sound in air.

With a thermometer take the temperature of the air in the neighbourhood of the glass tube. Let it be t°C. Then the velocity in air $= 332 + 0.6t$ m. per second. (TEXT-BOOK, § 163.)

Calculate this velocity and divide it by the wave-length of the sound in air to obtain the frequency of the note ($v=nl$.)

As the rod is clamped at the middle the length of the rod is one-half of the wave-length of the sound in glass, and hence the wave-length in glass is equal to twice the length of the rod. Find this wave-length.

Finally, multiply the wave-length of the sound in glass by the frequency of the note to obtain the velocity of sound in glass.

NOTE.—A glass rod is easiest to vibrate but it breaks easily. Instead of it a rod of brass or of wood may be used. These can be put in vibration by stroking with leather covered with powdered rosin. A mitten faced with chamois answers very well.

*Experiment 46.—To find the vibration-frequency of a tuning-fork.

APPARATUS:—The apparatus (Fig. 50) consists of a large tuning-fork with a light aluminium or brass style, or a bristle, attached to one prong; a pendulum which beats approximately quarter-seconds with a style extending below the bob (which should be heavy); and a piece of smoked (or whitened) glass, about 10x30 cm., on a carriage which can be drawn along under the two styles. The glass may be smoked by holding it over a lamp-flame, with the chimney removed, or even over a candle; it is much cleaner, however, to coat it with a mixture of whiting in alcohol or of "Bon Ami."

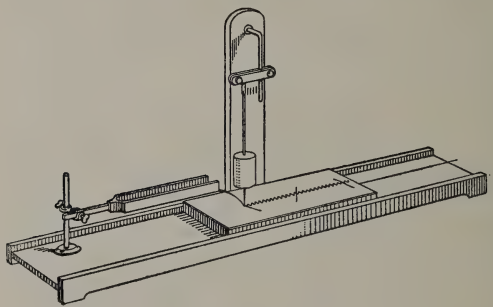


Fig. 50.—Comparing the frequency of a pendulum and a tuning-fork.

Method.—Adjust the height of the pendulum so that the style barely touches the coated surface of the glass. Then carefully adjust the tuning-fork so that its style bears lightly on the glass, and when vibrated makes a stroke on the glass parallel to the pendulum's motion across the glass. Both motions should also be at right angles to the direction of

motion of the glass when pulled along on its carriage. The two styles when at rest should be as near together as practicable.

Set the tuning-fork in vibration by bowing it. When it is going properly draw the pendulum aside and let it swing, and then quickly draw the glass along beneath the styles. The writing on the glass will be like Fig. 51. Between A and B or B and C is a single swing of the pendulum. Count the number of vibrations of the fork between the first and the last swing of the pendulum recorded on the glass. Next, count the number of vibrations of the pendulum per minute and deduce the time of a single one. Then calculate the number of complete (*i.e.*, to-and-fro) vibrations of the tuning-fork in one second.

Fig. 51.—The trace of the tuning-folk and the pendulum.

***Experiment 47.—To determine the vibration-frequency of a tuning-fork (or stretched string, organ-pipe, etc.)** (Text-Book, § 184.)

Apparatus:—Metal disc with several concentric circles of holes drilled through it, rotator (preferably motor driven), revolution counter, tuning-fork or other source of sound, source of compressed air.

Method.—Make the disc rotate and direct the compressed air through a nozzle placed opposite one of the rows of holes (Fig. 52.) Set the tuning-fork vibrating and compare the two notes. Then alter the speed of the rotator, using if necessary a different row of holes, until the pitch of the note emitted by the siren

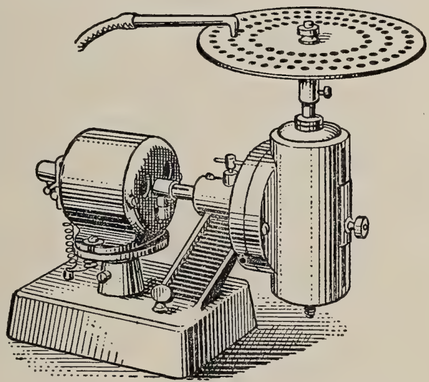


Fig. 52.—Air is blown through the holes in the rotating plate.

is the same as that of the fork. This will be the case when the beats just disappear. (Text-Book, §§ 211, 212.)

Now keep the speed of rotation constant and by means of the revolution counter ascertain the number of revolutions which the disc is making per second. Then find the vibration-frequency by multiplying this number by the number of holes in the circle used.

If a fork is available whose note is the octave of that of the fork just used, determine its frequency by the same method. What relation do you observe between the frequencies of the two forks?

***Experiment 48.—To investigate the laws of vibrating strings.** (Text-Book, §§ 192, 193.)

Apparatus:—Use a sonometer holding at least two strings. One of these is fixed at one end, while at the other end it is wound about a post which may be turned with a key, thus altering the tension as desired. The other string is fastened at one end, while at the other it passes over a pulley and has a hook on the end of it to which weights may be added. Let the first string be of steel wire No. 22; we shall call this string A. In addition have a second steel string of the same gauge, which will be called string B; and a steel string No. 28 gauge (*i.e.*, with a diameter one-half that of the other). Call this latter string C.

Method.—1. *Investigate the relation between length and pitch.* Stretch string B with sufficient weight (6 or 8 kg.) for it to give, when plucked by the finger or excited by a violin bow, a good musical note. Then alter the tension of string A until the two strings are in unison. Do this by listening for the beats produced when the two strings are sounded together. When unison is obtained there will be no beats. (Text-Book, §§ 211, 212.)

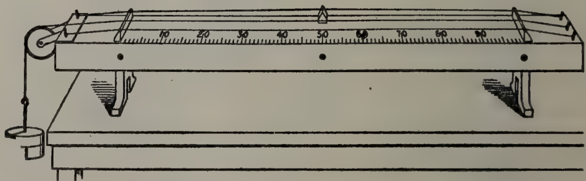


Fig. 53.—A sonometer, consisting of stretched strings over a thin wooden box. By means of a bridge we can use any part of a string.

Now place a bridge under string B a few cm. from one end and pluck the longer portion of the string, pressing the short portion down on the bridge. What effect on the pitch? Move the bridge until a length is reached which gives a note an octave above the original string. Compare by plucking string A. If one note is an octave above another, it has twice as many vibrations per second. Measure the length required. What relation do you observe as to length and number of vibrations?

Mark off on the sonometer lengths which are respectively $\frac{8}{9}, \frac{4}{5}, \frac{3}{4}, \frac{2}{3}, \frac{3}{5}, \frac{8}{15}, \frac{1}{2}$ of the original length. Sound the notes given by these lengths. They produce the major diatonic scale, the frequencies of which are in the ratios 1, $\frac{9}{8}, \frac{5}{4}, \frac{4}{3}, \frac{3}{2}, \frac{5}{3}, \frac{15}{8}$, 2. What law do you observe between pitch and length?

2. *Relation between pitch and tension.* Apply a tension of 3 kg. to string B, and tune A to be in unison with it. Then place the bridge so as to use one-half of A and add weights to B to bring it into unison with one-half of A. Compare the new with the old pitch, and the new with the old tension. What relation do you find?

3. *Relation between pitch and diameter.* Put a weight of, say, 6 kg. on string B, and adjust the tension of A until it is in unison with B again. As the strings are of the same diameter, length and material, it is clear that string A is also under a tension of 6 kg. Now substitute string C for string B and add the same weight, 6 kg. Thus strings A and C are under the same tension. Pluck C; its pitch is much higher than that of A. Adjust the bridge under A until you obtain a length which gives a note in unison with that given by C. Measure this length. What is the difference in pitch between strings C and A when at full length? Measure with a wire gauge the diameter of the wire.

What relation do you observe between pitch and diameter? State the three laws you have verified.

***Experiment 49.—To investigate the nodes and loops of a vibrating string.** (Text-Book, §§ 171, 194.)

Apparatus:—Sonometer and some small paper riders. (Fig. 54.)

Method.—Damp the string at the centre by touching it lightly with a feather or with the tip of the finger. Place a rider, made by folding a piece of paper, as shown in the figure, at the middle of one of the halves, and bow the string at the middle of the other half. How does the rider behave? How is the string vibrating?

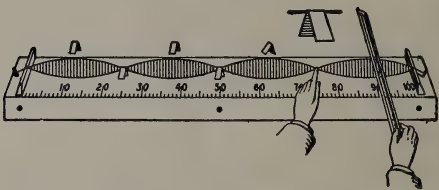


Fig. 54.—Obtaining nodes and loops in a vibrating string. The paper riders stay on at the nodes, but are thrown off at the loops.

Repeat the above experiment, damping the string at one-third its length from one end, placing riders on the string at $\frac{1}{6}$, $\frac{1}{3}$ and $\frac{1}{2}$ its length from the other end. How do the riders behave? Where are the points of least motion in the string? Where the points of greatest motion? How is the string vibrating?

Repeat the last experiment, damping the string at a point $\frac{1}{4}$ and then $\frac{1}{5}$ of its length from one end. How does the string vibrate in each case? How does the note which the string yields differ from that produced when it vibrates as a whole?

What are the points of least motion called? What those of greatest motion?

Experiment 50.—To show interference of sound-waves. (Text-Book, §§ 213, 214.)

Apparatus:—That shown in Fig. 48, (page 50) and in Fig. 55.

Method.—1. Adjust the length of the air column over the water (Fig. 48) until it resounds most loudly when the fork is vibrated over the mouth of the tube. Then rotate the fork

on its axis. Describe any changes in the sound. At what position of the fork is the sound loudest? At what position is it most feeble? Holding the fork in the position of weakest sound, carefully slip over one prong a small paste-board tube. What effect on the loudness of the sound?

2. Hold a vibrating fork near the ear and rotate it about its axis. Describe the sound, and account for the changes in it.

3. Tune two wide-mouthed bottles to resonance with the fork. In order to do this, hold the vibrating fork over the mouth of the bottle, and then carefully slip a piece of glass over it until the bottle resounds loudly. Then fasten the glass in place with soft wax. Now arrange the bottles as shown in the figure. Bring the fork slowly down to the position shown in the figure. What change in the sound occurs as the fork is put in this position? Hold a card over one mouth; what change in the sound? Account for this.

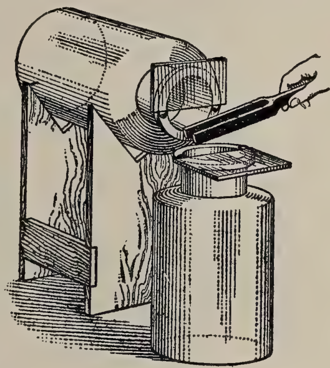


Fig. 55.—Interference with resonators.

*Experiment 51.—To find the wave-length of a sound by interference in a divided tube.

Apparatus:—The apparatus consists essentially of two large **T**-tubes connected by rubber tubing (Fig. 56). Another form of apparatus is shown in the experiment following this.

Let a sounding tuning-fork be placed before the open tube *A*. The sound passes along the tube and is divided by the first **T**-tube into two portions. One portion goes by way of the tube *C*, the other by way of the tube *B*, to the second **T**-tube, by which they are brought together again at *D*. Thence the motion is conveyed by the two tubes which lead to the ear. *B* and *C* are double tubes, one slipping snugly within the other.

It is evident that if the difference in the lengths of the tubes *B* and *C* is a half-wave-length of the sound used, the two components on reaching

D will be in opposite phases, condensation in one will coincide with rarefaction in the other, and each will annul the effect of the other. Under

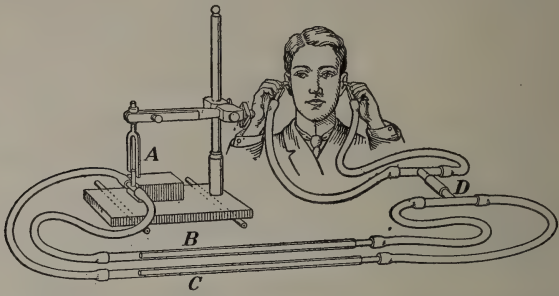


Fig. 56.—The fork A is held in a clamp of a retort stand which rests on rubber tubing to prevent the sound from being transmitted to the table on which it is placed.

these circumstances the two portions *interfere*, and there should be practically no sound heard at the ear.

Method.—A fork whose frequency is between 300 and 400 complete vibrations per second should be used. Let one student vibrate the fork before A, and another place the ends of the tubes in his ears. By slipping one glass tube over the other, vary the difference in the lengths of B and C, and carefully adjust it until the sound is weakest. Pinch one of the rubber tubes to compare the effects obtained by using one component and the two combined. Since the sound is transmitted not only within the tubing, but also by the material of the tubing, it will be impossible to extinguish the sound completely.

Having found the adjustment which gives the weakest sound, measure the lengths of the two paths, ABD, and ACD. Twice the difference between the two lengths is the wave-length of the sound.

If the frequency of the fork is known, calculate the velocity of sound from the formula $v = nl$; if it is not known, determine the frequency from the same formula, taking the velocity in metres as $332 + 0.6t$, where t is the temperature in degrees centigrade.

***Experiment 52.—To find the wave-length of a sound by means of a divided tube.**

APPARATUS:—The apparatus is shown in Fig. 57. It consists of two brass tubes, *A* and *B*, connected by telescoping joints, with short side-tubes inserted at *C* and *D*.

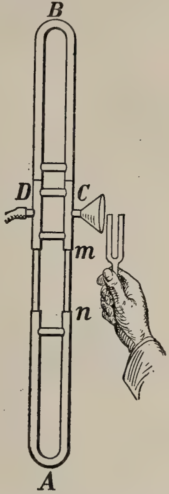


FIG. 57.—Interference apparatus.

Method.—Adjust the tube *A* so that the distance from the opening *C* to the opening *D* is the same around the tube in the direction *CAD* as in the direction *CBD*. Connect *D* with your ear by means of rubber tubing and place a tuning-fork before the opening in *C*. Vibrate the fork. The sound is heard clearly. It reaches the ear through both branches simultaneously.

Now draw *A* out until the intensity of the sound is a minimum. With proper adjustment the sound will almost disappear. In this case the length of the path *CAD* is one-half wave-length longer than the path *CBD*. Measure the difference between the two paths and calculate the wave-length.

Experiment 53.—To test the freezing and the boiling-point of a thermometer. (TEXT-BOOK, § 239.)

APPARATUS:—Convenient apparatus is shown in Figs. 58, 59.

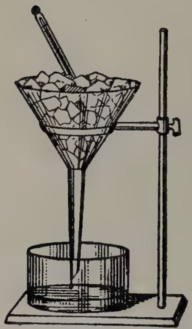


FIG. 58.—Apparatus for testing the freezing-point.

Method.—The freezing-point. Insert the thermometer into a funnel (Fig. 58), containing clean ice broken into small pieces, packing the ice well about it. Allow it to remain for some minutes, until the mercury will fall no further, and then carefully take the reading. In doing so have the eye in such a position that a line drawn from it to the top of the mercury column is at right angles to the thermometer, and estimate the reading to tenths of a degree.

Is the thermometer graduated correctly?

The boiling-point. Arrange apparatus as in Fig. 59. The flask is about half-full of distilled water and the bulb of the thermometer should be about 1 cm. above the water.

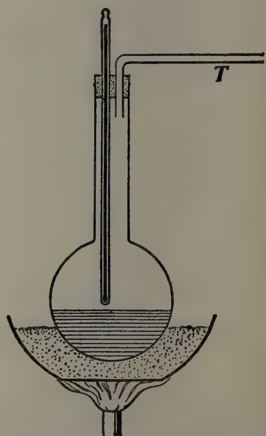


FIG. 59.—Apparatus for testing the boiling-point.

Heat the water until it boils and then keep it boiling quietly so that the stem of the thermometer is surrounded by steam, which escapes through the tube *T*. Read the thermometer after the mercury becomes steady and record its height. Then read the barometer and compute the true boiling-point, being given that at 76 cm. the boiling-point is 100° C., and an increase of 1 cm. raises the boiling-point

0.4° C.; at 29.92 inches the boiling-point is 212° F., and an increase of 1 inch raises it 1.7° F.

How much in error is the thermometer?

Experiment 54.—To find the coefficient of linear expansion of brass. (TEXT-BOOK, § 244.)

APPARATUS:—*AB* (Fig. 60) is a brass tube about 6 mm. in diameter and 105 cm. long, connected to a Florence flask or other boiler by a rubber tube *T*. The open end *A* rests on a block with the end against a nail driven in the block. A weight *W* keeps this end in place. Exactly one metre from the end *A* a shallow cut *C* is made in the wall of the tube by using a hack-saw or a file and the tube is supported at this point on the edge of a piece of thin sheet metal *M*, 2 cm. high, to which is attached a wire *P*, 20 cm. long, to serve as a pointer. A centimetre scale *S* is placed behind the pointer.

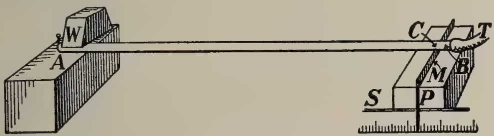


FIG. 60.—Simple apparatus for finding the coefficient of linear expansion of a tube.

Method.—Note the temperature of the air in the room and take this as the initial temperature of the brass. Record also the division on the scale opposite the end of *P*. Then bring the water to the boiling-point and let the steam pass through the tube for a few minutes, taking care not to disturb the apparatus. The piece of metal *M* and the pointer *P* act like a lever with the fulcrum at the line where the metal meets the block. When the pointer stops moving, record its new position. The second temperature of the rod is that of steam and may be found by placing a thermometer in the steam in the boiler.

Arrange your observations as follows:—

Initial length of tube	100 cm.
Distance through which pointer moved	cm.
Elongation of rod ($\frac{1}{10}$ scale distance)	cm.
Initial temperature of brass	°C.
Final temperature of brass	°C.

Work out the coefficient of linear expansion, that is, the expansion per centimetre length for one degree rise in temperature.

*Experiment 55.—To find the coefficient of linear expansion of a metal rod. (Text-Book, § 244.)

Apparatus:—The arrangement shown in Fig. 61 is well suited for this experiment. *B* is a boiler half-filled with water. *T* is a horizontal brass jacket tube covered with non-conducting material. Two smaller tubes, *H*, *K*, are soldered into this tube, steam entering at one and passing out at the other. A third tube at the middle, closed by a cork, has a thermometer *G* fitted into it. The rod to be experimented on is placed within *T*, which is closed by conical metal caps which keep the rod central in *T*. This tube is carried on a rigid base, being held securely in place by clips. There are two uprights *A* and *C*, one at each end, firmly fastened to the base. One of these carries an adjusting screw *E*, and the other a micrometer *S*, which should read to 0.01 mm.

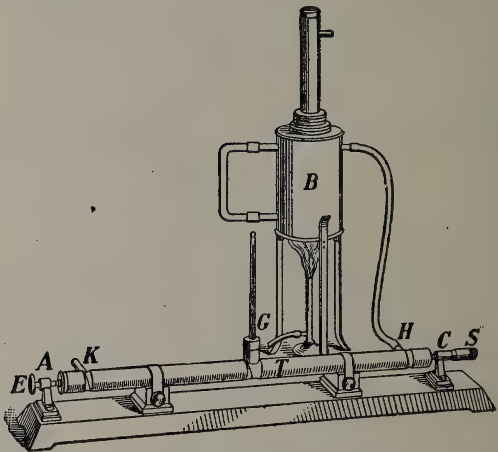


Fig. 61.—Apparatus for finding the coefficient of linear expansion of a metal rod.

Method.—First measure the length of the rod by means of a metre stick. Then place it in the jacket *T*, and, having one end firm against the screw *E*, turn the micrometer screw *S* until it makes gentle contact with the other end. Take the reading of the micrometer and also that of the thermometer, which gives the temperature of the rod. Then turn the screw back two or three rotations to allow for the expansion of the rod.

Now connect the boiler and allow the steam to pass freely through *T* for some time, until the rod has had time to be heated through and the thermometer is steady. Catch the condensed steam in a vessel placed under *K*, not on the base of the apparatus. Then turn the micrometer screw until it again makes gentle contact with the end of the rod. Record the temperature and read the micrometer. The micrometer readings must be taken with great care since the expansion is a very small quantity and any error made in measuring it will make a great difference in the final result.

Tabulate results as follows:—

Length of Rod in mm.	Temperature		Micrometer		Increase in Temperature	Expansion in mm.	Expansion for 1° C.
	First	Last	First	Last			

The coefficient of linear expansion is the expansion per degree per unit of length, and is obtained by dividing the last column by the first. Calculate it and compare its value with that given in the appendix.

Repeat the experiment, if possible. Accurate results are not easy to obtain.

Experiment 56.—To compare the expansions of water and alcohol. (Text-Book, § 245.)

Apparatus:—Having secured two small flasks, as nearly alike as possible, fill one with water, the other with alcohol. The temperature of each should be the same. Insert glass tubes of the same bore, which should be small, into two corks and push these into the flasks until the liquid rises to the same height in each, as shown on an attached paper scale (Fig. 62).

Method.—Allow the flasks to stand until you are sure they have the temperature of the room, which is read by a thermometer placed near them; then note the height at which the liquid stands in each tube. Next, place the two flasks in a vessel containing water a few degrees above the room temperature. Watch closely any change in the heights of the liquids in the tubes. Allow them to stand for some time until they take the temperature of the water, and record the heights and the temperature. Then raise the temperature by heating or by pouring in warm water, and again take the temperature and the heights of the columns. Continue this until the alcohol is nearly at the boiling-point or the liquids are at the top of the small tubes.

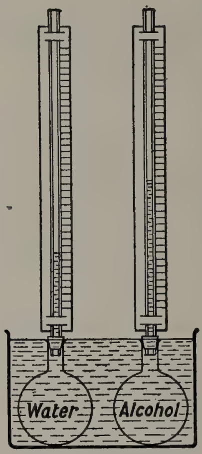


Fig. 62.—To compare expansions of liquids.

Which liquid expands the more with the heat?

Remove one flask from the hot water and plunge it into cold water; watch closely any change in the height of the liquid column. Explain this behaviour.

On a sheet of squared paper draw curves to represent the expansion of each liquid, ordinates indicating increase in height of the liquid and abscissas increase in temperature.

Which curve is steeper? What does that indicate?

Experiment 57.—To find the coefficient of apparent expansion of turpentine. (Text-Book, § 245.)

Apparatus:—Specific gravity bottle, beaker, thermometer, retort stand, etc. (Fig. 63).

Method.—Weigh the specific gravity bottle and fill it with

turpentine at the temperature of the room. Replace the stopper and carefully wipe off the excess of liquid which has overflowed. Weigh the bottle again and take the room temperature.

Next bring the water in the beaker to a temperature slightly above that of the room and immerse the bottle in it, so that the neck is just above the surface of the water. Heat the water to about 80° C. and maintain this temperature. When the turpentine stops coming out of the hole, wipe off the top of the stopper, remove the bottle, dry carefully and allow it to cool. Then weigh the bottle and its contents once more.

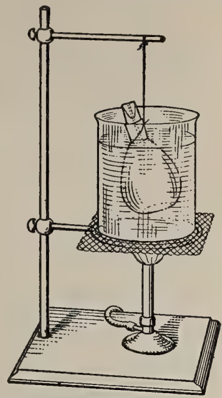


FIG. 63.–Apparatus for finding the coefficient of apparent expansion of turpentine.

Record your observations and calculate your result as in the following numerical example:—

Observations:—

Weight of bottle empty	20.00 gm.
1st weight of bottle and turpentine	125.70 gm.
2nd weight of bottle and turpentine	120.32 gm.
Temperature of room	20° C.
Temperature to which turpentine was heated	75° C.

From which

Turpentine lost through expansion	5.38 gm.
Increase in temperature	55° C.

Calculation:—

Let us call a "volume" of turpentine the volume which weighs 1 gm. at 20° C.

Then,

100.32 volumes heated 55 degrees expand 5.38 volumes.

$$1 \text{ volume heated 1 degree expands } \frac{5.38}{100.32 \times 55} = .00097 \text{ volumes,}$$

or coefficient of apparent cubical expansion (in terms of volume at 20° C.) = .00097.

NOTE.—1. The coefficient of expansion of a liquid is usually stated in terms of the volume at 0° C.

2. To obtain the coefficient of absolute expansion we should add the coefficient of cubical expansion of glass.

***Experiment 58.—To study the expansion of water near the freezing-point.** (TEXT-BOOK, § 246.)

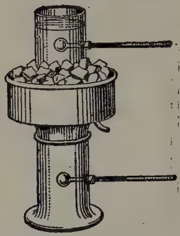


FIG. 64.—Hope's apparatus.

APPARATUS:—Hope's apparatus (Fig. 64). It consists of a cylindrical glass or metal vessel surrounded at about half its height by an annular trough, and having two thermometers inserted through holes in the sides, one at the top, the other at the bottom.

Method.—Fill the cylinder with water at a temperature of 8 or 10° C., and in the trough put a mixture of snow (or pounded ice) and salt. Then observe every minute, or half-minute, the readings on the two thermometers. It is well to surround the apparatus with some non-conducting material such as felt or cotton wool.

Enter your observations thus:—

TIME											
UPPER THERMOMETER											
LOWER THERMOMETER											

Draw curves to represent the variation in the temperatures with the time, ordinates representing temperatures and abscissas representing times.

Why does the lower thermometer fall first? At what temperature has water its maximum density? Explain the great importance of this fact in nature.

NOTE.—To perform the experiment requires 40 or 50 minutes.

Experiment 59.—To find the coefficient of expansion of a gas (Charles' Law). (TEXT-BOOK, § 247.)

APPARATUS:— A fine glass tube about 60 cm. long, closed at one end and containing a column of dry air imprisoned by a short thread of mercury (Fig. 65), a tall jar, a thermometer and a metre stick.

Method.—Tie the tube and thermometer to a metre stick and place it in the jar in a vertical position. Surround it with water to which enough chopped ice or snow has been added to bring the temperature as close as possible to 0° C. When the air in the tube ceases to contract, note the temperature and also the length of the air column.

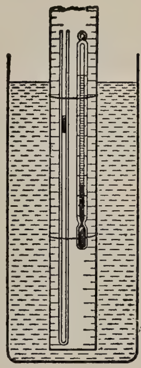


FIG. 65.—Apparatus for measuring the expansion of a gas.

Next fill the jar with water at about 50° C and note the new length of the air column and the new temperature after the air has ceased to expand.

Finally repeat the readings with the tube immersed in water at about 80° C.

Tabulate the observations as follows:—

READING	TEMPERATURE	CHANGE IN TEMP.	LENGTH OF AIR	CHANGE IN LENGTH
1	0° C.			
2		(from 1 to 2)		(from 1 to 2)
3		(from 1 to 3)		(from 1 to 3)

Since the area of the cross-section of the tube is uniform the volumes of the air at the different temperatures are proportional to the lengths, and consequently the numbers which represent the lengths can also be used to represent the volumes.

From the observations taken, calculate the increase of a unit volume of air at 0° C. per degree rise in temperature.

Two results can be obtained from the observations taken. Average these two results.

State your conclusions as follows:—

I find that the volume of a given mass of gas at constant pressure increases for each rise of 1° C. by $\frac{1}{***}$ of its volume at 0° C.

NOTE.—If it is not desired to immerse the metre stick in water, the tube can be held close to the side of the jar and the measurements can be taken from the outside.

Experiment 60.—To study the method of mixtures. (TEXT-BOOK, § 250.)

APPARATUS:—Beakers, thermometer, balance, stirrer.

Method.—Place a beaker on one pan of a balance and add shot or other small objects to the other pan until the beaker is counterpoised. Then add 200 grams more, and pour water into the beaker until equilibrium is again obtained. Have the temperature of this water 8 or 10 degrees lower than that of the room. Pour this into another beaker. Then replace the first beaker on the balance and pour in 300 grams of water which is at a temperature 4 or 5 degrees above that of the room. (For this experiment, instead of weighing the water it may be measured in a graduate, assuming that 1 c.c. = 1 gram).

Now take a third beaker, large enough to hold all the water which has been weighed. Stir the cooler water well and take its temperature; do the same for the warmer water. Then pour the water from the two beakers into the third one, stir it well and take the temperature. It is more satisfactory to have two thermometers, one for each beaker, so that there may be no change in one temperature while the other is being taken, but if no time is wasted this change can be neglected.

Calculate now how many calories of heat have been gained by the colder water, and how many lost by the warmer. It

is evident that these should be equal, except for any heat that may have been lost or gained by the third beaker.

Why was the temperature of one chosen above that of the room and that of the other below it?

Experiment 61.—To find the thermal capacity and water equivalent of a calorimeter and the specific heat of the metal of which it is made. (TEXT-BOOK, § 252.)

APPARATUS:—Calorimeter (Fig. 66. For a description, see TEXT-BOOK, § 254), thermometer, balance, Bunsen burner, beakers.

Method.—Weigh the vessel A (Fig. 66). Pour in tap water, which should be at least five degrees below the temperature of the room, until it is about half-full, and weigh again. Subtract, to find the weight of the water. Then place A in the outer vessel B and after stirring the water well take its temperature. (Use the thermometer as stirrer.)

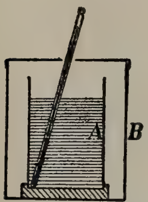


FIG. 66.—A calorimeter.

Have water heated in a beaker to about 20 centigrade degrees above the room temperature. Take its temperature and then pour into A enough to nearly fill it. Stir well and take the temperature. Finally weigh the vessel A and its contents again and calculate the weight of the warm water poured into the calorimeter.

It is evident that the heat given out by the warm water is equal to the heat gained by the cold water and the calorimeter.

Tabulate your observations and calculate your results as in the following numerical example:—

Observations:—

Weight of calorimeter	243.3 grams
Weight of calorimeter + cold water	663.7 "
Temperature of calorimeter and cold water...	12.8°C.
Temperature of warm water	42.0°C.
Final temperature of mixture	23.2°C.
Weight of calorimeter + cold + warm water	908.7 grams

From which,

Weight of cold water .... = 420.4 grams
Weight of warm water .... = 245.0 "

Calculation:—

Heat lost by warm water = 245 (42.0 − 23.2) = 4606 cal.
Heat gained by cold water = 420.4 (23.2 − 12.8) = 4372.2 cal.
∴ Heat gained by calorimeter = 233.8 cal.
∴ Thermal capacity of calorimeter = 233.8 ÷ (23.2 − 12.8) = 22.5 cal. (approx.).

Water equivalent of calorimeter = 22.5 gm.
Specific heat of metal = 22.5 ÷ 243.3 = .092.

Experiment 62.—To find the specific heat of lead or copper shot. (Text-Book, § 253.)

Apparatus:—Cylindrical metal dipper or large test-tube to contain the shot, Florence flask or beaker to act as a boiler, burner, balance, thermometer, calorimeter.

Method.—Fill the dipper or test-tube three-quarters full of shot and carefully insert the bulb of a thermometer in the shot. Then place the vessel containing the shot in the flask (Fig. 67) and heat the water to the boiling-point.

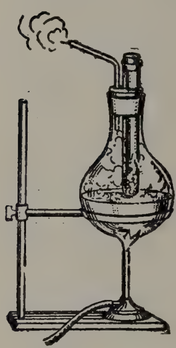


Fig. 67.—Determination of specific heat of a solid.

Weigh the calorimeter, add about 200 c.c. of tap water, which should be about 5 degrees below the temperature of the room, and weigh again to find the weight of the water added.

After the temperature of the lead has ceased rising, record it. Withdraw the thermometer, let it cool and then take the temperature of the water in the calorimeter.

Next, take the thermometer out of the calorimeter, remove the vessel holding the shot from the flask (use a cloth to handle it) and immediately pour the lead into the calorimeter. Stir with the thermometer until the temperature of the water stops rising, and then read its temperature. Finally, weigh again to find the mass of the shot.

Tabulate your observations and calculate the specific heat of the shot, as in the following numerical example:—

Observations:—

Weight of calorimeter (copper)	104.2 gm.
Weight of calorimeter + cold water	306.6 "
Weight of calorimeter + water + shot	606.9 "
Initial temperature of water	14.2 °C.
Temperature of shot	100.0 °C.
Final temperature of water and shot	19.0 °C.

From which,

Weight of cold water .... =	202.4 gm.
Weight of shot .... =	300.3 "
Fall in temp. of shot .... =	81.0 °C.
Rise in temp. of water and calorimeter ...... =	4.8 °C.

Calculation:—

Heat gained by water = $202.4 \times 4.8 = 971.5$ cal.
Heat gained by calorimeter = $104.2 \times .094 \times 4.8 = 47.0$ cal.
Total heat gained by cold bodies = 1018.5 cal.
This is equal to the heat lost by shot.

$$\therefore \text{ Specific heat of shot } = \frac{1018.5}{300.3 \times 81.0} = .042.$$

NOTE.—In this solution the specific heat of copper has been used in calculating the heat gained by the calorimeter. If the thermal capacity or water equivalent of the calorimeter is already known the solution is slightly simplified.

Experiment 63.—To find the melting-point of paraffin or of beeswax. (TEXT-BOOK, §§ 255, 256.)

APPARATUS:—Heat some small glass tubing in a flame and draw it out into a fine tube. Cut off a piece a few inches long, dip the fine end in melted paraffin, and then fuse the end of the tube in the flame. (If the tube is very fine it may be held in the melted wax and then used without being fused at all). Thermometer, retort stand, wire gauze, Bunsen burner, beaker.

Method.—Bind the tube to a thermometer so that the wax is near the bulb, and then hold it in a beaker of water to which heat is applied gradually (Fig. 68). Keep the water well stirred, and note carefully the temperature when the wax becomes transparent at the lowest part of the tube.

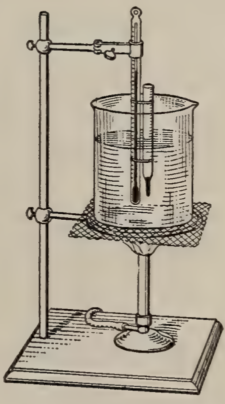


FIG. 68.—Finding the melting point of paraffin.

Next, remove the heat and let the

water cool, and observe the temperature when the wax becomes opaque again. Take the mean of these two temperatures as the melting-point.

Experiment 64.—To study the effect of pressure on the boiling-point. (TEXT-BOOK, § 267.)

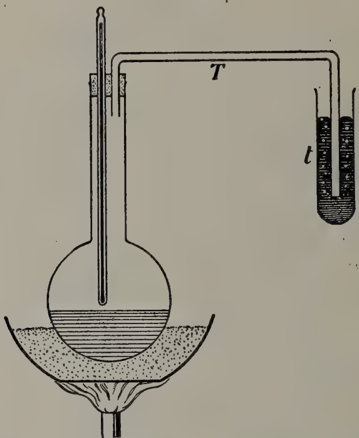


FIG. 69.—Boiling-point under increased pressure.

APPARATUS:—As shown in Figs. 69 and 70.

Method.—Pressures greater than atmospheric. Arrange the apparatus as in Fig. 69. The flask should be half-full of distilled water and the bulb of the thermometer should be about one centimetre above the surface of the water. The test-tube t contains mercury.

Find the boiling-point of the water before the end of the tube T is immersed in the mercury. Then find the boiling-points when the end of T is 1, 2, 3, 4 and 5 cm. below the surface of the mercury. Read the barometer and tabulate the observations as follows:—

BAROMETER	DEPTH OF T	STEAM PRESSURE	BOILING-POINT
...... cm.	1 cm.	...... cm.	...... °C.
	2 "	...... "	......
	3 "	...... "	......
	4 "	...... "	......
	5 "	...... "	......

Pressures less than atmospheric. Half-fill a round-bottomed flask with water and boil for a minute or two to expel the air. Then remove the flame and immediately close the flask with a good stopper. Invert the flask, support it on a retort stand (Fig. 70), and pour cold water over the flask. Observe the action in the flask and state your conclusion.

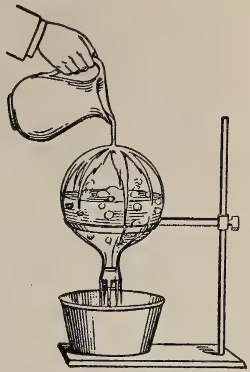


FIG. 70. — Boiling-point of a liquid lowered by decrease of pressure.

Experiment 65.—To study the effect of salt upon the boiling-point of water.

APPARATUS:—That shown in Fig. 71. The flask should have a capacity of about 300 c.c. If an ordinary flask is used, two holes should be bored through the cork, one for the thermometer, the other for a glass tube.

Method.—Measure out 150 c.c. of water and pour it into the flask. Heat the flask carefully, protecting it from the flame by wire gauze, until the water boils. First, have the thermometer bulb in the steam above the water. What temperature does it show? Let it boil for a few minutes; does the temperature change? Then push the bulb down into the water. What is the temperature? Does it remain steady? Next, add 10 grams of salt, and boil. Place the bulb in the solution, and note the temperature. Then remove the thermometer, wipe the bulb, and replace it so that the bulb is in the steam above the solution. Again note the temperature. Repeat these observations, using 20, 30, etc., grams of salt until the solution becomes saturated.

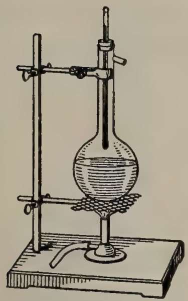


FIG. 71.—Find the boiling-point of a salt solution.

State in your note-book what is the effect on the boiling-point of water by adding common salt to it, and also what is the effect on the steam rising from it.

Make a boiling-point curve with grams of salt as abscissas and boiling-points (obtained with the thermometer in the liquid) as ordinates.

Experiment 66.—To find the lowest temperature obtainable with a mixture of snow and salt. (TEXT-BOOK, § 262.)

APPARATUS:—Tumbler or other vessel to contain snow and salt, thermometer.

Method.—Mix well together the snow (or broken ice) and salt, and insert in it a thermometer which reads to about $-20°C$. Use varying quantities of salt, and see how low a temperature is obtainable.

Experiment 67.—To determine the cooling curve through change of state (solidification). (TEXT-BOOK, §§ 255, 256.)

APPARATUS:—Very small test-tube, two larger test-tubes, vessel to contain freezing mixture, thermometer, mercury.

Method.—1. *For paraffin.* Heat some paraffin contained in a test-tube to about 60°C.; place a thermometer in it and observe it regularly at intervals of 1 minute as the wax cools in the air. The paraffin should be heated by holding the tube in water which is heated by a gas or other flame.

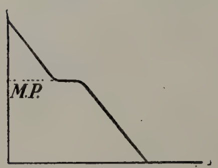


FIG. 72.—A cooling curve.

Plot a curve (Fig. 72), having temperatures for ordinates and time for abscissas.

2. *For water.* A similar experiment can be tried with water, a suitable arrangement being shown in Fig. 73. The water, which should be distilled, is held in a large test-tube,

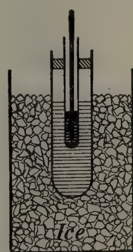


FIG. 73.—Apparatus for obtaining cooling curve for water.

and the thermometer is in a thin-walled test-tube containing mercury and just large enough to admit the thermometer.

The large tube is packed in a freezing mixture of snow and salt. Read the temperature every half-minute, and plot a curve as above.

Experiment 68.—To find the heat of fusion of ice. (Text-Book, §§ 259, 260.)

Apparatus:—Calorimeter, thermometer, balance.

Method.—Weigh the calorimeter. Half-fill it with water at a temperature of 30 or 35° C. Weigh again, and thus obtain the mass of the water. Take some pieces of ice, having a mass about one-sixth that of the water. Stir the water well and take its temperature. Dry the ice with a towel or a flannel cloth, and quickly drop it into the water. Stir (by means of the thermometer or other stirrer), and observe the lowest temperature reached by the water. Again weigh the calorimeter and its contents, and by subtraction find the weight of the ice added.

Tabulate your observations and find the heat of fusion as in the following example:—

Observations:—

Weight of calorimeter (aluminium, sp. ht. .21) ..		25 gm.
Weight of calorimeter and water		225 "
Initial temperature of water		20° C.
Temperature after ice has melted..............		10.3° C.
Weight of calorimeter, water and melted ice		247 gm.
From which,		
Weight of water at 20° C..................	=	200 gm.
Weight of ice melted	=	22 "
Fall in temperature of water and calorimeter	=	9.7° C.

Calculation:—

Heat lost by water = 200 × 9.7..........	=	1940 cal.
Heat lost by calorimeter = 25 × 9.7 × .21	=	50.9 cal.
Total heat lost by hot bodies	=	1990.9 cal.

Heat required to raise 22 gm. water from
0 °C. to 10.3° C. = 22 × 10.3 = 226.6 cal.

Heat required to melt 22 gm. ice = 1764.3 cal.

∴ Heat required to melt 1 gm. ice = 1764.3 ÷ 22 = 80.2 cal.

Experiment 69.—To find the heat of vaporization of water. (Text-Book, §§ 269, 270.)

Apparatus:—That shown in Fig. 74 is very convenient. A Florence flask may be used instead of the special boiler.

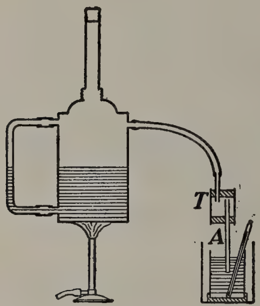


Fig. 74.—Finding the latent heat of steam. The trap T is made from a glass tube about 2 inches long and 1 inch diameter, with a glass tube through a cork in each end.

Method.—Weigh the calorimeter. Fill it two-thirds full with the coldest available tap water, and weigh very carefully again, to find the weight of the water.

Now have steam coming freely from the boiler and passing by means of a rubber tube into a trap T. Introduce the delivery tube A into the calorimeter, thrust it 2 or 3 cm. below the surface of the water, and keep up a vigorous current of steam. This will be shown by a noisy and incessant collapse of bubbles as they come in contact with the cold water.

Keep stirring the water and when its temperature has risen to about 35° C. quickly remove the delivery tube. Stir the water thoroughly and quickly and take its temperature. Then with no unnecessary delay weigh the calorimeter and its contents. This weighing should also be made with much care. Subtract the last weight from this one and thus obtain the weight of the steam which has entered the water.

Tabulate observations and calculate the heat of vaporization of water as in the following example:—

Observations:—

Weight of calorimeter (brass)	50 gm.
Weight of calorimeter and water	300 "
Initial temperature of water	5° C.
Temperature after introducing steam	30° C.
Weight of calorimeter, water and condensed steam	310.5 gm.

From which,

Weight of water at 5° C	=	250 gm.
Weight of steam condensed	=	10.5 gm.
Increase in temperature of water and calorimeter	=	25° C.

Calculation:—

Heat gained by the water = 250 × 25	=	6250 cal.
Heat gained by the calorimeter = 50 × 25 × .090	=	112.5 "
Total heat gained by cold bodies	=	6362.5 "
Heat lost by condensed steam in cooling from 100° C. to 30° C. = 10.5 × 70	=	735.0 cal.
∴ Heat lost by 10.5 gm. steam in condensing	=	5627.5 "
Heat lost by 1 gm. steam in condensing	=	536 cal. (nearly)

Notes: 1. The trap is used to catch any water condensed from the steam in the pipes and prevent it from trickling into the calorimeter. It can be dispensed with entirely. In Fig. 75 is shown a simple form of the apparatus, in which no trap is used.

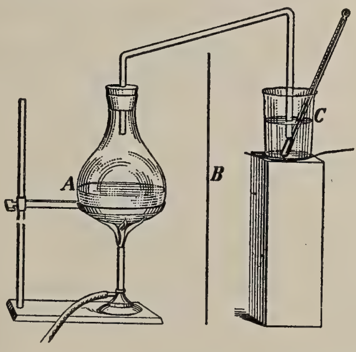


FIG. 75.—Simple apparatus for finding heat of vaporization. *B* is a screen to protect the calorimeter *C* from the source of heat. Water condensed in the delivery tube runs back into the flask.

2. As the latent heat is high the quantity of steam used is small and care must be taken in the weighings. A small error in the weight of the steam will make a considerable error in the result.

Experiment 70.—To find the dew-point and the relative humidity. (Text-Book, §§ 276-279.)

Apparatus:—A polished thin metal cup (Fig. 76), thermometer.

Method.—Half-fill with tap water a thin polished metal cup—one of aluminium or of nickel-plated brass will answer well. Continue dropping small pieces of ice in, stirring well all the time, until dew is seen to form on the outside. Then take the temperature of the water with a thermometer which should be read to $\frac{1}{10}$ of a degree. This temperature is probably a little below the dew-point.

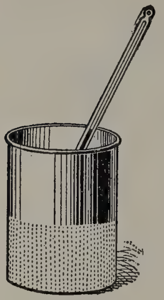


Fig. 76.—A polished metal cup for finding the dew-point.

Now add small quantities of water at the temperature of the room until the mist begins to disappear, and then take the temperature again. This will probably be a little higher than the dew-point. Take the mean of the two temperatures as the dew-point.

Repeat the experiment several times. After one or two trials the temperature found going down will be quite close to that found going up.

Be careful not to breathe upon the outside of the vessel or to hold any damp object near it while looking for the mist to form. A sheet of glass stood in front of the apparatus will protect it.

If a thick layer of moisture forms upon the vessel before the reverse process is begun, it should be wiped off.

From the table in the appendix find the number of grams of water vapour in 1 cu. metre of saturated air at the dew-point and also at the room temperature. Then calculate the relative humidity.

***Experiment 71.—To find the relative humidity by use of a chemical hygrometer.** (TEXT-BOOK, § 278.)

APPARATUS:—As shown in Fig. 77. *A* is a large bottle of at least 10 litres capacity. The **U**-tubes *C*, *D* and *E* contain calcium chloride or some other substance which absorbs water-vapour readily. The bottle *F* contains strong sulphuric acid. *G* and *H* are thermometers.

Method.—Have *A* nearly full of water at the beginning of the experiment. The temperature of the water, which is determined by the thermometer *G*, should not differ materially from that of the air, as read by the thermometer *H*. Weigh the tubes *C*, *D*, *E* carefully and then place them in position.

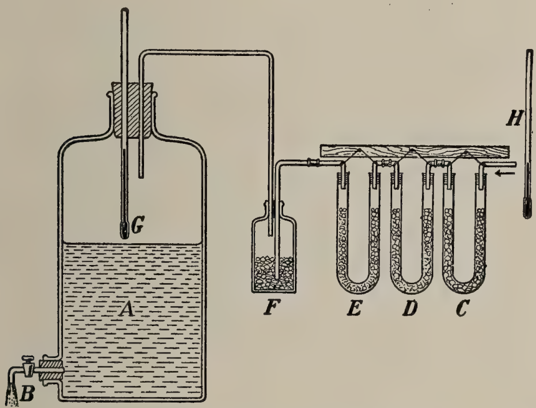


FIG. 77.—A chemical hygrometer for actually weighing the water-vapour present in a given volume of air.

Open the tap *B* and catch the water as it runs out in a measuring vessel, which should be fairly large to avoid too frequent emptying. Fill and empty *A* at least five times if time permits. Calculate the volume of water which has escaped through the tap *B*; this will be approximately equal to the volume of air which has passed through the **U**-tubes.

Next, remove the **U**-tubes and weigh again carefully to find the amount of water-vapour absorbed.

Now attach to *C* a **U**-tube containing sponge saturated with water and repeat the experiment. The air which is drawn through *C*, *D* and *E* should, under these conditions, be saturated with water-vapour. Draw approximately the same volume of air through the tubes and weigh them again with the same care.

From the results, calculate the amount of water-vapour present in 1 litre of the air in the room and also in 1 litre of saturated air at the same temperature. Express the former as a per cent. of the latter. This will give the relative humidity.

Note.—This experiment is most satisfactory in warm weather, not in the winter when there is little moisture in the atmosphere.

Fig. 78. — Wet-and-dry bulb hygrometer.

Experiment 72.—To find the relative humidity by using the wet-and-dry bulb hygrometer. (Text-Book, § 280.)

Apparatus:—Two thermometers which should be as nearly correct as possible. The bulb of one of the thermometers is covered with muslin kept moist by a wick which dips in a vessel of distilled water. (Fig. 78.)

Method.—Read the thermometers carefully when the bulbs are dry, and if there is any difference in the readings, record it. Then immerse the wick in the water and when the mercury in the wet-bulb thermometer ceases to fall note the readings again. Correct these readings for any initial error.

Compute the relative humidity from the table given at the back of this Manual.

Note.—If Fahrenheit thermometers are not available, use Centigrade thermometers and reduce their readings to the Fahrenheit scale.

***Experiment 73.—To find the relative conductivities of some metals.** (TEXT-BOOK, §§ 294, 295.)

APPARATUS:—The apparatus, devised by Edser, is illustrated in Fig. 79. *A* is a vessel, which may be made from a piece of brass tubing 10 cm. in diameter and 20 cm. long, the bottom being closed by a brass disc. Holes are bored in this to receive rods of different metals (about 2.5 mm. in diameter and 15 cm. long) soldered in position perpendicular to the bottom. Each rod is provided with a small index made from copper wire about 0.8 mm. in diameter (No.20 wire), bent in the form shown enlarged at *B*. The indexes are made by winding the wire on rods slightly larger than the rods in the bottom of the vessel.

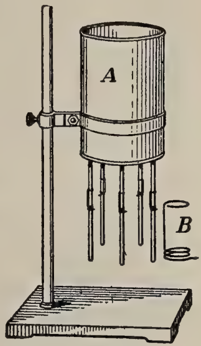


FIG. 79.—Edser's apparatus for finding relative conducting powers of metal rods.

Method.—To begin with, invert the vessel *A*, slip an index on each rod, and melt a very small amount of paraffin wax around the rings. When the vessel is turned right-side-up, as shown in the figure, the solid wax holds the indexes in position.

Now pour boiling water into the vessel. As the rods get heated the wax is melted and the indexes slip down, carrying the wax before them; and when the temperatures of the rods have acquired steady values, the indexes will have descended to points on the various rods where the wax just solidifies, and which therefore possess equal temperatures.

Now measure the distances from the bottom of the vessel to the projecting point on each index. It has been proved (in works on the theory of conduction of heat) that the conducting powers are proportional to the squares of these distances. Find the squares of the distances measured, and taking the conductivity of copper as 100, compute the conductivities of the other rods.

Perform the experiment several times: it does not take long to do it.

***Experiment 74.—To determine (approximately) the mechanical equivalent of heat; i.e., to find the amount of energy which is equivalent to unit quantity of heat.** (TEXT-BOOK, §§ 285, 286.)

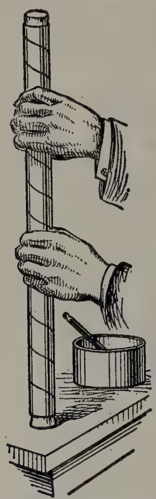


FIG. 80.—Finding the mechanical equivalent of heat.

APPARATUS:—A stout cardboard tube about 1 m. long and 5 cm. in diameter, about 500 gm. of lead shot 1.5 mm. in diameter, and a delicate thermometer. (Fig. 80.)

Method.—Fit each end of the tube with a sound cork, and insert one cork. Place the thermometer in the shot, which may conveniently be held in a cardboard box, and read the temperature accurately. Let it be t_1°C.

Now pour the shot into the tube, holding it in an almost horizontal position, and then, turning the tube upright, measure the distance from the upper surface of the shot to the place where the lower surface of the upper cork reaches when it is inserted in the tube. Let this distance be h cm.

Next insert the upper cork, take hold of the middle of the tube and quickly invert it so that the other end comes uppermost. The shot will drop to the bottom. Repeat this 100 times, then quickly thrust a thermometer into the shot through a hole made in the side of the tube and take the temperature. Let it be t_2°C.

Calculate the mechanical equivalent of heat as follows:—

$$\begin{aligned}
\text{Let } m \text{ grams} &= \text{mass of the shot,} \\
s &= \text{specific heat of lead.} \\
\text{Then mechanical work done} &= 100\ mh \text{ gram-centimetre units,} \\
&= 100\ mgh \text{ ergs.} \\
\text{And heat developed} &= ms\,(t_2 - t_1) \text{ calories.} \\
\left.\begin{array}{r}\text{Hence the mechanical work} \\ \text{equivalent to 1 calorie}\end{array}\right\} &= \frac{100\ mgh}{ms\,(t_2 - t_1)} = \frac{100\ gh}{s(t_2 - t_1)} \text{ ergs.}
\end{aligned}$$

Repeat the experiment, making 150 inversions of the tube.

NOTE.—In performing the experiment make sure of the correct specific heat of the shot. In some cases it differs considerably from that of pure lead. See Experiment 62.

Experiment 75.—To study the images produced through small apertures. (TEXT-BOOK, §§ 313, 314.)

APPARATUS:—Use a box about 4 inches square and 8 inches long. Over an opening in one end fasten a piece of tin-foil, and cover the other end with thin paper, tracing cloth or ground glass.

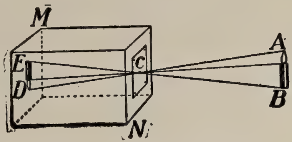


FIG. 81.—A pin-hole camera.

Method.—Place a candle or an incandescent lamp in front of the box, and pierce a hole in the tin-foil with a pin. Observe the image on the ground glass by covering the head and the back of the camera with a dark cloth.

Note the position (erect or inverted) of the image, also how clear or sharply defined it is. Measure the height of the candle and of its image, and their distances from the pin-hole. Place the candle at different distances and measure these quantities for each distance. Arrange the results in a table, thus:—

HEIGHT OF OBJECT	HEIGHT OF IMAGE	$\frac{\text{HT. OF OBJECT}}{\text{HT. OF IMAGE}}$	DISTANCE OF OBJECT FROM PIN-HOLE	DISTANCE OF IMAGE FROM PIN-HOLE	$\frac{\text{OBJ. FROM PIN-HOLE}}{\text{IM. FROM PIN-HOLE}}$

Now make a three-cornered or an oblong hole in the tin-foil. Do you notice any difference in the image? Make the first hole larger. What change in the image? Make several holes

near together. What result? Now make them all into one hole, and note the result.

In your note-book describe all your experiments and the results observed. Also make a sketch showing why the images are inverted; and answer the following questions:—

(*a*) What relation do you observe between the size of the object and the size of the image?

(*b*) On what does the brightness of an image depend?

(*c*) On what does the sharpness of definition depend?

***Experiment 76.—To verify the law of inverse squares.** (Text-Book, § 324.)

Apparatus:—A simple but efficient photometer can be made from two blocks of paraffin wax, 6 or 7 mm. thick and about 2.5 cm. square. They should be cut from the same slab of paraffin, carefully made of the same thickness and then placed together with a sheet of tin-foil between them (*a*, Fig. 82). They may be simply set on a stand, or may be placed at

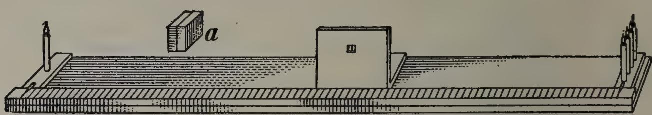


Fig. 82.—A paraffin-block photometer.

the back of a piece of wood or metal with a hole about 1 cm. square in it, the blocks being so arranged that an equal amount of each is seen through the aperture. This, as well as the board on which it moves, should be painted black, and the experiment should be performed in a darkened room. If this photometer cannot be obtained, use a Bunsen or a Rumford photometer.

Method.—At one end of the blackened board place one candle, and at the other (1 m. or more away) place four candles (Fig. 82). Have the candles all burning equally well. Now move the photometer back and forth until the two portions of paraffin are equally bright. If the two lights are of the same

colour, as they are in this case, the tin-foil line of separation will disappear. If the colours are not identical, one must judge when the two portions are equally bright. This can be done quite accurately after a little practice. Make 2 or 3 adjustments of the photometer, measuring the distance from the lights to the photometer each time. Let the distance from the single candle to the photometer be d_1, that of the four candles be d_2. Take the average of your values of d_1 and d_2.

Then change the distance between the lights and, adjusting the photometer as before, obtain new values for d_1 and d_2 and take the average again.

Repeat this with another distance between the lights. Tabulate your results thus:—

From 1 Candle to Photometer, d_1	From 4 Candles to Photometer, d_2	$\left(\frac{d_2}{d_1}\right)^2$

These experiments may be further extended by using 9 candles in place of the 4, in which case the ratio $\left(\frac{d_2}{d_1}\right)^2$ should be equal to 9.

Experiment 77.—To compare the powers of an electric lamp and a wax candle by using a shadow photometer.

Apparatus:—25-watt tungsten (or 8 c.p. carbon) electric lamp, lamp socket with flexible cord, ordinary wax candle, cardboard screen, retort stand, metre stick.

Method.—Arrange the apparatus as in Fig. 83. The rod of the retort stand should be about 10 cm. from the screen and the distance from the candle to the screen about 30 cm. Darken the room and move the electric lamp until the two

shadows are of equal intensity. Best results will be obtained when the two shadows are quite close to each other.

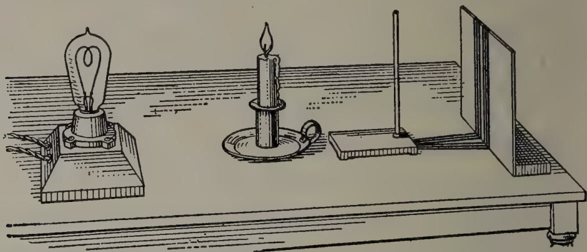


Fig. 83.—Finding the candle-power of an electric lamp by means of the shadow photometer.

Measure the distance from the lamp to the screen carefully and then repeat the experiment with the candle at 35 and 40 cm. from the screen.

Tabulate your results as follows:—

Candle to Screen	Lamp to Screen	$\left(\frac{\text{Lamp to Screen}}{\text{Candle to Screen}}\right)^2$	Power of Lamp *(in terms of candle)*
		Average Power	

Note.—1. In performing this experiment care should be taken to keep the candle flame at the same height for the different readings.

2. A paraffin block or a Bunsen grease-spot photometer may be used instead of the shadow photometer.

Experiment 78.—To establish the law of reflection. (Text-Book, § 328.)

Apparatus:—As a mirror use preferably a strip of unsilvered thin plate-glass about 1 inch wide and 3 inches long. A microscope slide answers well. Blacken one face of the glass and then attach it to a rectangular block of wood, with the blackened face against the wood. This may be

done with passe-partout binding tape. The reason for not using a piece of ordinary mirror is that it is silvered on the back, while it is best to have reflection from the front surface. Sheet of paper on board.

Method.—1. Draw a straight pencil-mark AB (Fig. 84) across the sheet of paper, and lay the block on it so that the front face (which is the reflecting face) of the mirror is along this line. The face of the mirror should be perpendicular to the paper; when such is the case the paper in front of the mirror and its reflection in the mirror appear to be one continuous plane.

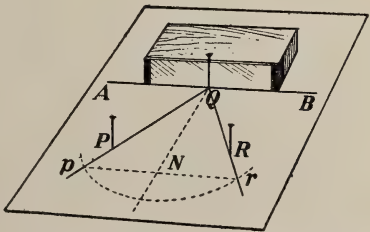


FIG. 84.—Arrangement for testing the law of reflection.

Stick a pin Q through the paper against the surface of the mirror and another pin P at some distance from Q in an oblique direction. Next close one eye and move the head slowly to the right until Q and the image of P appear in line. Then insert the pin R so that R, Q and the image of P are seen in a straight line. (In doing this, sight at the level of the paper in case the pins are not exactly vertical).

Remove the mirror and the pins, and with a fine pencil draw the lines PQ, RQ. Also, with a set-square or with compasses, draw the perpendicular QN to AB. It is evident from our experimenting that if PQN is the angle of incidence, RQN is the angle of reflection. With a protractor measure each of these angles. If a protractor is not at hand, with centre Q describe a circle cutting PQ and RQ in p and r respectively. Join pr and measure pN, rN with a millimetre scale.

Repeat, with another position of P.

In your note-book copy the figure on a reduced scale and mark the angles and lengths on it. State your conclusion.

2. Place the pin P directly in front of the mirror, first at a distance of 5 cm. from it (Fig. 85). Observe the image and move a second pin Q around behind the mirror until it coincides with the image. (See "Method of Parallax," TEXT-BOOK,

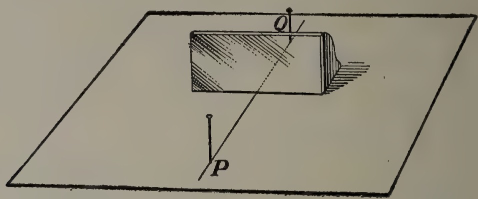


FIG. 85.—Finding the position of the image by parallax.

§ 328.) Remove the mirror and join PQ. Measure the angle which PQ makes with the line on which the mirror was placed and also the distance that the image is behind the mirror.

Repeat, making $P = 6, 8, 10$ cm. from the mirror.

Tabulate results as follows:—

PIN TO MIRROR	IMAGE TO MIRROR	ANGLE BETWEEN PQ AND MIRROR
5 cm.		
6		
8		
10		

State your conclusion.

Experiment 79.—To show that when a mirror is rotated through an angle the reflected ray is rotated through twice that angle.

APPARATUS:—The same as in the last experiment. (Fig. 84.)

Method.—First, adjust the pins P, Q and R as in the previous experiment. Then turn the mirror about Q through an angle of about 5° and draw a line along its face to show its new position. Let this be $A'B'$. Also find the new position of R. Let it be R'. Then QR' is the direction of the new reflected ray.

With the protractor measure the angle between AB and $A'B'$, and also between QR and QR'. (Fig. 86.)

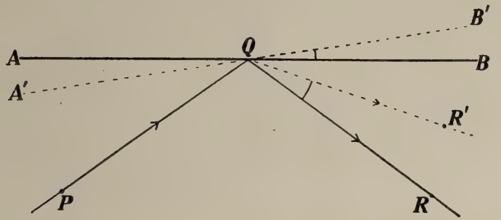


FIG. 86.—AB is first and $A'B'$ is second position of mirror; QR is first reflected ray and QR' second reflected ray.

Continue rotating the mirror through small angles and determining the direction of the reflected ray, and measure the angles in each case between the new position of the mirror and the first position, also between the new direction of the reflected ray and the first direction.

Arrange your results in a table thus:—

ANGLE TURNED THROUGH BY MIRROR	ANGLE TURNED THROUGH BY REFLECTED RAY

What conclusion can you draw?

Experiment 80.—To study the images in a plane mirror. (TEXT-BOOK, §§ 332, 333.)

APPARATUS:—A plane mirror and a penknife.

Method.—Stand the mirror on a table and place a penknife, with the small blade opened 90°, upright before the mirror. Where does the image appear to be? Turn the open blade so

as to point towards the mirror. In what direction does the image point? Hold the right hand before the mirror. Which hand does it appear to be in the image? What name is given to this apparent changing of sides?

Open both blades out fully and lay the knife on the table with the point of one blade touching the mirror. Where does the image appear to be? Continually increase the angle made with the mirror by the knife and note the image in each case.

Lay the knife on the table 3 or 4 inches from the mirror. Note the position of the image. Turn the mirror through about 30°, and note the position of the image again.

Make drawings to locate the position of the image in all the above cases.

Experiment 81.—To study the images in parallel mirrors. (TEXT-BOOK, § 334.)

APPARATUS:—Two plane mirrors, candle.

Method.—Place two mirrors vertically on a table parallel with, and facing each other, and place a lighted candle between them. Now look obliquely into one mirror just over the edge of the other.

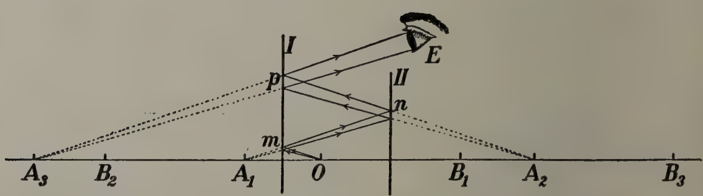


FIG. 87.—Showing many images produced by two mirrors *I*, *II*, parallel to each other.

How do you account for the large number of images seen? What limit is there to the number formed? Account for their positions in the same straight line? To answer this question draw the rays by which any three successive images are seen.

Experiment 82.—To study the images in inclined mirrors. (Text-Book, §§ 335, 336.)

Apparatus:—Two plane mirrors, candle, protractor.

Method.—Place upright on a table two plane mirrors meeting at an angle of 90°. The angle can be determined by having the mirrors rest upon a sheet of paper on which is drawn a circle graduated in degrees, the line in which the mirrors meet being at the centre of the circle.

Stand a candle between the mirrors. How many images can be seen? Make a drawing to locate the images, and also show on it how the light passes from the candle to the eye.

Repeat the experiment with mirrors inclined at 60°, 45°, 72° and 40°.

Experiment 83.—To find the radius of curvature and focal length of a concave spherical mirror. (Text-Book, §§ 342, 343.)

Apparatus:—Mounted concave mirror having a radius of curvature of about 50 or 60 cm., screen, lamp, metre stick.

Method.—1. Hold the mirror in the sunlight so that the rays fall directly upon it, and receive the image on the edge of a white card or a narrow strip of paper held in front of the mirror. Move the screen until the image is smallest and most distinct. The distinctness of the image can often be improved by using only the central portion of the mirror. To do this, cut a round hole about 2 cm. in diameter in a piece of brown paper and place this over the mirror. Having obtained the sharpest possible image on the screen, measure its distance from the vertex of the mirror. This is the focal length, which is one-half the radius of curvature.

2. If you cannot use direct sunlight obtain the image of a bright window as far off as possible, or, still better, of a telegraph pole, chimney or tree outside the window.

3. In a piece of card-board make a hole 6 or 7 mm. in diameter, and across it stretch two black threads or pieces of fine wire (Fig. 88). They may be held in place by wax or by a label pasted over their ends. Mount the card on an upright so that the cross-threads are at the same height as the vertex of the mirror. Illuminate the threads by placing a strong lamp behind. Now move the mirror so that a distinct image of the hole falls on the card-board just beside the hole itself. When this is the case the cross-threads are at the centre of curvature of the mirror. Measure the distance from the cross-threads to the vertex; this is the radius of curvature.

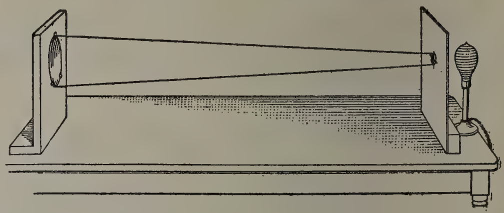


FIG. 88.—Finding the radius of curvature of a concave mirror

4. By means of conjugate foci. If p is the distance of an object from the mirror, p' the distance of its image and r the radius of curvature (Fig. 89), then it can be shown (see page 151) that

$$\frac{1}{p}+\frac{1}{p'}=\frac{2}{r}.$$

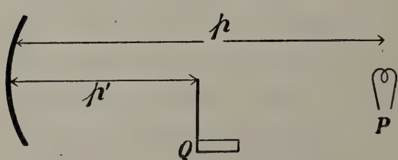


FIG. 89.—P is object and Q is image.

Use an electric lamp or candle as object and focus the image on a screen. Measure p and p' for three different positions of the object and image. Calculate r in each case and average the results.

Experiment 84.—To study the positions and characteristics of the images produced by a concave mirror. (TEXT-BOOK §§ 343, 344.)

APPARATUS:—As in the preceding experiment; also two mounted hat-pins.

Method.—1. Find the position of the image of the sun or of a tree or window as far away as possible. Measure the distance from the image to the mirror and note the characteristics* of the image.

2. Using the candle or the lamp as object, find the position and characteristics of the image for two positions of the object *beyond* the centre of curvature (say at 150 and 100 cm. from the mirror).

3. Find the position where object and image are equidistant from the mirror. Note carefully the size of the image and also its other characteristics.

4. Find the position and characteristics of the image for two positions of the object between the centre of curvature and the principal focus.

5. Using a hat-pin stuck in a cork or a block of wood as object and a similar arrangement as 'finder,' find the position and characteristics of the image for two positions of the object between the principal focus and the mirror (Fig. 90). In this

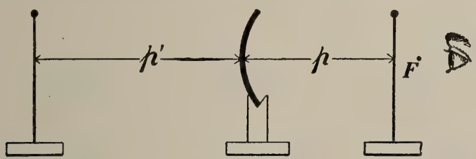


FIG. 90.—Finding the image of an object placed between the principal focus and the mirror.

case the method of parallax (TEXT-BOOK, § 328) must be used to locate the image. The finder should be placed behind the mirror and the part of it visible above the mirror should be aligned with the image as seen in the mirror.

*Real or virtual, erect or inverted, enlarged or diminished.

Tabulate your observations as follows:—

Object to Mirror	Image to Mirror	Characteristics
cm.	cm.	

State your conclusions by filling in the following table, in which C stands for centre of curvature, F for principal focus and A for vertex of the mirror.

Concave Mirror

Position of Object	Position of Image	Characteristics of Image
At infinite distance........		
Beyond C.................		
At C.....................		
Between C and F.........		
At F		
Between F and A.........		

Draw diagrams (Text-Book, § 344) to show how the position of the image can be located geometrically when the object is (*a*) beyond C, (*b*) between C and F, (*c*) between F and A.

Experiment 85.—To study the images produced by a convex mirror and to find its focal length. (Text-Book, § § 343, 344.)

Apparatus:—Mounted convex mirror having a radius of curvature of 50 or 60 cm., piece of rather thick wire stuck in a cork or a piece of wood to act as object, hat-pin similarly mounted to serve as finder, metre stick.

Method.—1. Locate the position and note the characteristics of the images when the object is 150, 100 and 50 cm. from the mirror. The image is virtual and its position is found by the method of parallax. Place the object before the mirror

and then move the finder about behind the mirror until it coincides with the position of the image. When this takes place there is no relative motion of one to the other if the eye is moved from side to side. If difficulty is experienced on account of the smallness of the image, use the rod of a retort stand or the edge of a metre stick as object for the longer distances (Fig. 91).

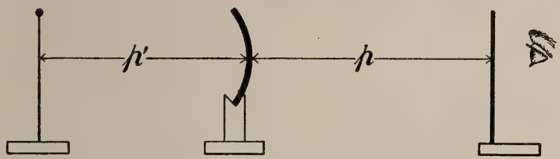


FIG. 91.—Finding the image produced by a convex mirror.

Tabulate your results as follows:—

OBJECT TO MIRROR, p	IMAGE TO MIRROR, p'	CHARACTERISTICS
150 cm.		
100 "		
50 "		

Next, using the formula $1/p + 1/p' = 2/r$ (see page 151), calculate the radius of curvature and the focal length of the mirror in each of the above cases, and take the average of the results. (Note that p' is negative, since the image is behind the mirror).

2. Using a chimney, a telegraph pole, or a 2 in. × 4 in. scantling as far away in the room as possible, as an object "at infinity," find the position of the image. Measure the distance between the finder and the mirror. This will approximate very closely to the focal length. Compare this result with that obtained by the method just described.

State the conclusions you can draw regarding the images formed in convex mirrors and make a drawing to show how the image can be located geometrically. (TEXT-BOOK, § 344.)

Experiment 86.—To find the index of refraction of glass. (Text-Book, §§ 348, 351.)

Apparatus:—For this experiment we require a rectangular block of plate-glass about 1.5 cm. thick, 6 or 8 cm. wide and of any convenient length. The edges should be polished, so that one can see from edge to edge through the glass. Metric rule graduated to millimetres, pins, paper on board.

Method.—Draw a straight line AB on the sheet of paper and place the block so that an edge is on the line (Fig. 92). Stick a pin upright at the point P against the edge of the glass plate, and another at Q against the opposite edge, so that the line joining P and Q is oblique to AB.

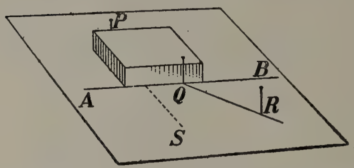


Fig. 92.—Arrangement for finding the index of refraction of a glass block.

From the direction S look with one eye along the paper *through* the glass at the pin P. Slowly move the eye towards R, looking continually through the glass at the pin P. To make sure that you are really seeing it, lay something on the top of the glass to hide the top of the pin. You will notice that the image seen through the glass is in a different direction from that seen over the glass.

Continue moving the eye, keeping it about a foot from the glass block, until the *image* of pin P is just hidden behind pin Q. Then place a pin R in the line from the eye to Q, *i.e.*, the pin R, the pin Q and the image of pin P all appear in a straight line. Sight at the level of the paper in case the pins are not precisely vertical.

Now remove the glass and the pins, and draw the lines PQ, QR and the perpendicular to AB at Q (Fig. 93). It is clear that the light which travelled along PQ in the glass, upon being refracted into the air, travelled along QR.

With centre Q describe a circle cutting the lines PQ, QR in C and D, respectively, and drop perpendiculars Cm, Dn. Then the index of refraction from glass to air is the ratio Cm/Dn, while that from air to glass is Dn/Cm, the inverse of this. Measure these distances with a mm. scale and calculate to two decimal places the value of Dn/Cm.

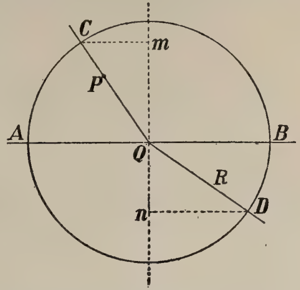


FIG. 93.—The ratio of Dn to Cm, which is equal to that of the sine of DQn to the sine of CQm, is the index of refraction from air to glass.

Repeat the experiment, taking three or four positions for P, not changing Q.

With a protractor measure the angles DQn, CQm, in each case, and using the table on page 152, calculate to two decimal places the ratio of their sines.

Arrange your results in the following table, and take the mean of your values for the index of refraction.

Dn	Cm	Dn/Cm	$\angle DQn$	$\angle CQm$	$\frac{\sin \angle DQn}{\sin \angle CQm}$
	Average			Average	

State the First Law of Refraction.

Experiment 87.—To trace the course of light through a prism and to find the angle of deviation. (TEXT-BOOK, § 359.)

APPARATUS:—Prism, drawing-board, pins, protractor.

Method.—Place the prism on a sheet of paper on the drawing-board and with a fine pencil draw lines along the sides AB and AC (Fig. 94).

Place a pin at R, about three inches from the prism, and another at P, close to the prism. Then look into the side AC and align two more pins Q and S with R and P as seen *through* the prism. In doing this, sight at the level of the board in case the pins are not absolutely vertical.

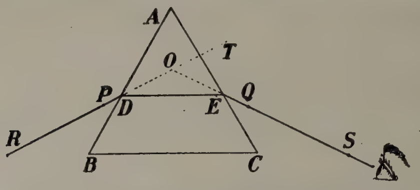


FIG. 94.—Tracing the course of light through a prism.

Next remove the prism and produce RP to meet AB at D and SQ to meet AC at E. It is evident that RD is an incident ray, ES is the corresponding emergent ray and DE is the path of the light through the prism.

Measure the angle TOS between RD the initial direction and OS the final direction of the light. This is the angle of deviation.

Repeat the experiment by varying the inclination of the ray RD. This can be done conveniently by leaving R in its original position and moving P to a new position.

Find the *least* value of the angle of deviation.

NOTE.—The angle of deviation is a minimum when the triangle ADE is isosceles.

Experiment 88.—To find the focal length of a converging lens. (TEXT-BOOK, § 365.)

APPARATUS:—Converging lens with a focal length of 15 or 20 cm., candle or carbon filament lamp, screen, metre stick.

Method.—1. Hold the lens in direct sunlight, receiving the image on a screen made of a white card or of ground glass. Move the screen back and forth until the image is as small and bright as possible. Then measure the distance from the screen to the centre of the lens. This is the focal length.

In the absence of the sun get the image of a bright window or of any bright object at a considerable distance—5 or 6 metres.

Make several adjustments for focus, measuring the focal length each time.

2. Adjust the candle (or incandescent lamp) and the screen until the image is distinctly formed on the screen when the candle and the screen are equidistant from the lens. When this is the case each is distant from the lens twice the focal length of the lens. Compare the sizes of object and image.

3. By conjugate foci. Place the candle at any distance from the lens and adjust the screen on the other side of the lens until the image is distinct. Let the distances of object and image from the middle of the lens be p and p', respectively. Then it can be proved (see page 151) that $1/p' - 1/p = 1/f$, where f is the focal length. Measure the distances p and p' and calculate f. (Observe that p is "+," and p' is "−." Should f come out "+" or "−"?)

Repeat this experiment several times, using different values of p, and take the average of the values of f calculated.

Make drawings showing the path of the light in all the above cases.

Experiment 89.—To study the positions and characteristics of the image produced by a converging lens. (Text-Book, § 365.)

Apparatus:—Converging lens, candle or incandescent lamp, screen, two hat-pins stuck in corks, metre stick.

Method.—1. Find the position of the image of the sun or of a tree or window as far away as possible. Measure the distance from the image to the middle of the lens and note the characteristics of the image.

2. Using the candle or lamp as object, find the position and characteristics of the image for two positions of the object *beyond* twice the focal length (say at 150 cm. and 100 cm. from the lens).

3. Find the position where object and image are equidistant from the lens. Note carefully the size of the image and also its other characteristics.

4. Repeat for two positions of the object between the principal focus and the point at twice the focal distance from the lens.

5. Using one hat-pin as object and the other as finder (Fig. 95), find the position and characteristics of the image for

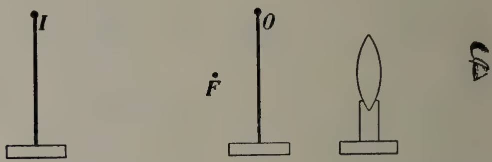


FIG. 95.—Finding the image of an object placed between the lens and its principal focus.

two positions of the object between the principal focus and the lens. In doing this be careful to look at the finder over the lens, disregarding its image as seen in the lens. (The image is farther away from the lens than the object and is on the same side of the lens).

Tabulate your observations as follows:—

OBJECT TO LENS	IMAGE TO LENS	CHARACTERISTICS

State your conclusions by filling in the following table:—

Position of Object	Position of Image	Characteristics
At infinite distance		
Beyond $2f$ from lens		
At $2f$ from lens		
Between f and $2f$ from lens		
At F		
Between F and lens		

Experiment 90.—To study the images produced by a diverging lens and to find its focal length. (Text-Book, §§ 365, 368.)

Apparatus:—Diverging lens (focal length about 25 or 30 cm.), hat-pin in cork to act as finder, thicker wire to act as object, metre stick.

Method.—1. Locate the position and note the characteristics of the image when the object is 150, 100, 50 and 25 cm. from the lens. To do this, place the finder between the object and the lens and adjust the finder as seen over the lens until it coincides with the image of the object as seen through the lens (Fig. 96).

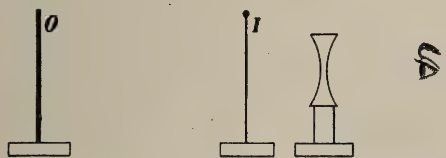


Fig. 96.—Locating the image produced by a diverging lens.

Tabulate your results as follows:—

Object to Lens, p	Image to Lens, p'	Characteristics
150 cm.		
100 "		
50 "		
25 "		

Now use the formula, $1/p' - 1/p = 1/f$, to determine the value of f from each set of readings and average the results. Here p, p' and f are all measured in the same direction and if p and p' are taken as +, f should be + also.

2. Locate the image of an upright stick (telegraph pole, chimney) at least five metres away. Measure the distance from the image to the lens. Compare this result with that obtained in (1).

State the conclusions you can draw regarding the images produced by a diverging lens. Make a drawing to show how the image can be located geometrically. (TEXT-BOOK, § 368.)

Experiment 91.—To find the focal length of a diverging lens (second method). (TEXT-BOOK, § 367.)

APPARATUS:—A diverging lens and a converging lens of shorter focal length.

Method.—First determine the focal length of the converging lens by one of the methods given in Experiment 88. Then find its power in dioptres by dividing 100 by the focal length in cm.

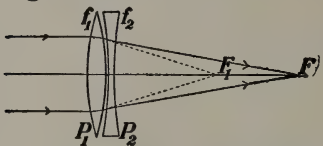


FIG. 97.—Finding the focal length of a concave lens by combining it with a convex lens.

Next, put the two lenses close together (Fig. 97) and find the focal length of the combination by the same method. Calculate the power of the combination also.

Finally calculate the power and focal length of the diverging lens as in the following numerical example:—

Focal length of converging lens		20 cm.
Power of converging lens		5 dioptres
Focal length of combination		50 cm.
Power of combination		2 dioptres
∵ Power of diverging lens..............	= −	3 dioptres
∴ Focal length of diverging lens........	= −	33⅓ cm.

Experiment 92.—To find the magnifying power of a simple microscope. (TEXT-BOOK, § 388.)

APPARATUS:—Simple microscope held on a retort stand, a millimetre scale. A linen tester is the most convenient form of microscope to use.

Method.—The simple microscope consists of a single converging lens or of several such lenses combined. In using it the eye is placed close to the lens, and the object to be examined is moved up until it is seen with the greatest distinctness. The ratio of the size that the object then appears to have to the size it appears to have when held at a distance of 25 cm. from the naked eye is called the *magnifying power* or *magnification.*

A convenient method of working is as follows. Lay a millimetre scale S on the base of a retort stand and hold the magnifier in a clamp at a height of 25 cm. above the scale (Fig. 98). Under this arrange a card C in which a square aperture has been cut. The breadth of the aperture may conveniently be about one-fourth the focal length of the lens. Measure the breadth carefully with a millimetre scale. Now bring the eye close to L and adjust the card C so that it is seen through the lens distinctly.

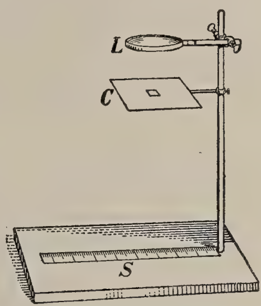


FIG. 98.—Finding the magnification of a reading lens.

Then, keeping both eyes open and having one close to the lens, observe the hole in the card through the lens with one eye and the metric scale directly with the other eye, and note the number of millimetres of the scale which correspond to the width of the hole. Divide this number by the number of millimetres in the width of the hole and the quotient will be the magnifying power.

In Fig. 99 is shown a linen tester. It will take the place of lens L and card C.

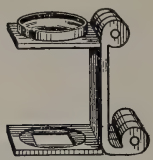


FIG. 99.—A linen tester.

Next, measure the focal length f cm. of the lens—which will be the distance from the card to the middle of the lens—and see how closely your observed value of the magnifying power agrees with the theoretical value $25/f$.

***Experiment 93.—To find the magnifying power of a telescope.** (TEXT-BOOK, § 390.)

APPARATUS:—A small telescope or "spy-glass," a metre stick.

Method.—Place a metre stick, on which the divisions are clearly marked, at the far end of the room. At the near end have the telescope held in a stand of some kind. Turn the telescope on the scale and focus it so that the divisions are seen distinctly. Now open both eyes, and look *along* the telescope with one, *through* it with the other.

At first it will probably be difficult to get clear images in the two eyes at the same time, that seen *through* the instrument appearing so much nearer. But by imagining that image to be at the far end of the room, and focussing the telescope with that idea in mind, after a little practice you will be able to see both clearly at the same time.

Adjust the direction of the telescope until the image seen through it is in line with the scale seen directly, and then observe the number of divisions seen through the telescope which correspond to the entire metre stick.

The magnifying power is the ratio of the total number of divisions on the scale to the number in the image which seem to cover it.

It will be advisable sometimes to have a scale longer than a metre, and a second student can assist by putting two bands

of white paper about a stick and then, following instructions from the observer, move them apart until the space between them appears to cover the entire stick. In such a case the stick need not be graduated.

***Experiment 94.—To construct an astronomical telescope.** (TEXT-BOOK, § 390.)

APPARATUS:—For this experiment we require two converging lenses, one having a focal length of 50 or 60 cm., that of the other being 3 or 4 cm. A convenient object to observe is a printed poster at the far end of the room. An incandescent lamp also forms a good object to look at.

Method.—Both lenses should be mounted on adjustable stands. Set the long-focus lens on a table facing the poster, and from some distance behind, look through the lens. An inverted image of the printing will be seen, on that side of the lens next the observer. Move a knitting-needle on a stand until it coincides with the image of the printing. To make sure that it really does coincide with it move the head from side to side; if the coincidence is exact there will be no motion of one with respect to the other. (Method of parallax.)

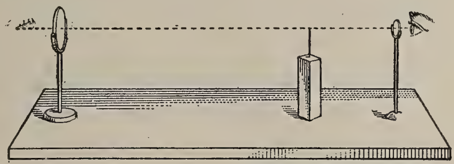


FIG. 100.—A model of an astronomical telescope.

Next place the small lens in line with the other lens and the needle, and adjust it so that an eye close to the lens sees the needle distinctly (Fig. 100).

Now remove the needle, and a magnified inverted image of the printing should be seen.

***Experiment 95.—To construct a Galilean telescope or opera-glass.**

APPARATUS:—In the ordinary opera-glass the objective is a converging lens, as in the ordinary telescope, but the eye-lens is diverging. Use a convex lens of 50 or 60 cm. focal length and a concave lens with focal length of about 5 cm.

Method.—As in Experiment 94 obtain an image of the object through the long-focus lens, and adjust the knitting-needle to coincide with it.

Then place the concave lens *between* the needle and the larger lens at about its focal length from the needle. Remove the needle and place the eye close to the concave lens. The image will be seen at once, and a slight adjustment of the concave lens will make it distinct.

***Experiment 96.—To construct a compound microscope.** (Text-Book, § 389.)

Apparatus:—For this experiment use two similar converging lenses of about 3 or 5 cm. focal length and 1 cm. or more in diameter. Through two corks bore holes a little smaller in diameter than the lenses, and fasten a lens to each cork by wax. Mount the two corks on stands. Tack a paper with small print on it upon a screen; this will act as object.

Method.—Approach one lens towards the paper until it is about double its focal length from it (Fig. 101). A real inverted image will be formed; adjust a mounted knitting-

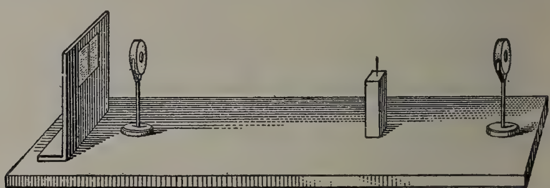


Fig. 101.—Illustrating the construction of a compound microscope.

needle to coincide with it. Next, adjust the second lens so that an eye close behind it sees the needle clearly. Then remove the needle, and a magnified image of the print should be seen.

If the print is brought nearer the first lens (the objective), the eye-lens must be moved farther away and the magnification will be increased; but this must not be carried too far or the image will become much distorted and indistinct.

Instead of holding the lenses on separate stands, the corks may be inserted in the ends of a tube about 4 or 5 times as long as the focal length of a lens. This can be used as a compound microscope.

***Experiment 97.—To study the spectrum.** (TEXT-BOOK, §§ 379-383.)

APPARATUS:—The only satisfactory apparatus to use for these experiments is a spectroscope. One with a single prism (Figs. 102, 103), or a direct-vision instrument will be quite satisfactory.

Method.—1. *Continuous spectrum.* Place before the slit of the spectroscope a gas-flame, a candle, an oil-lamp or an electric light. Focus the instrument so that the edges of the spectrum are seen distinctly. Describe the spectrum in each case. Is it equally long in every instance? Try the effect of widening and narrowing the slit.

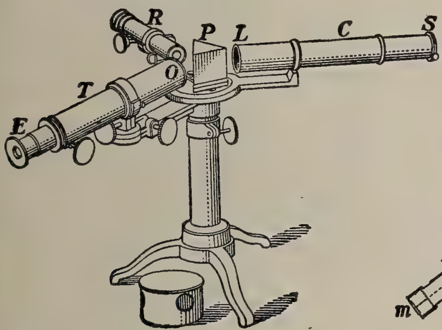


FIG. 102.—A single-prism spectroscope.

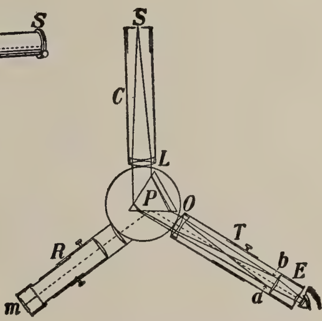


FIG. 103.—A horizontal section of a single-prism spectroscope.

2. *Bright-line spectra.* Have a Bunsen flame (or spirit lamp) a few inches in front of the slit of the spectroscope. Do you see any spectrum? While you are looking through the instrument let another student hold in the flame a piece of asbestos wick which has been soaked in a solution of sodium carbonate (washing soda). Describe the spectrum produced. Next try a solution of sodium chloride (ordinary table salt). Any difference?

Now try pieces of asbestos which have been dipped in solutions of the chlorides of lithium, thallium, strontium, calcium. Describe the spectrum seen in each case. In any of these latter substances did you see a yellow band like that seen with sodium? If so, can you explain how it got there?

3. *Absorption spectra.* Place before the slit of the spectroscope a very intense source of light, such as the oxy-hydrogen limelight or the electric arc light. The spectrum seen is continuous.

Between the intense source and the slit hold (1) a piece of ruby glass, (2) a deep blue glass, (3) a vessel with plate-glass sides having a dilute solution of permanganate of potash in it. Describe the spectrum in each case.

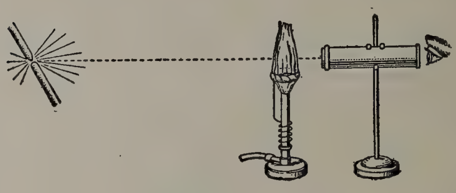


FIG. 104.—Light from the arc lamp passes through sodium vapour in the Bunsen flame and is then examined by the spectroscope. A dark band in the yellow is seen. The sodium vapour comes from the asbestos wick which has been soaked in a strong solution of common salt and is then held in the Bunsen flame.

Next, between the source and the slit place a Bunsen burner, and in the flame hold—on asbestos or in a metal spoon—some sodium salt, or, better, some metallic sodium (Fig. 104). We might naturally expect that this intense yellow flame would add to the yellow in the spectrum, but quite the reverse happens. There will appear a dark line in the yellow. Hold a screen between the source and the Bunsen flame, and the bright yellow line appears again.

Thus sodium vapour emits yellow light, the spectrum of which is a single line,* but when light from a hotter source passes through incandescent sodium vapour, so much of the

*In a more powerful spectroscope it will be found that there are really two lines close together.

yellow light is absorbed by the vapour that the lines appear dark in contrast with the bright background.

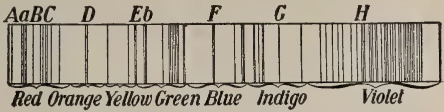


FIG. 105.—Showing some of the 'dark lines' in the spectrum of sunlight.

Point the spectroscope at the sun or at a bright cloud. When properly focussed, and using a narrow slit, a great number of dark lines are seen (Fig. 105). These are due to absorption. Can you suggest where the absorption takes place?

Describe all the experiments, with diagrams of the spectra, in your note-book.

Experiment 98.—To study the field about a magnet. (TEXT-BOOK, § 400.)

APPARATUS:—A bar-magnet, a jeweller's compass, sheets of paper preferably about 30 cm. square though foolscap will do.

Method.—Place a sheet of paper on the table, and lay upon it a bar-magnet 15 or 20 cm. long, the *N*-pole of the magnet being towards the north (Fig 106). With a sharp pencil draw a line about the magnet.

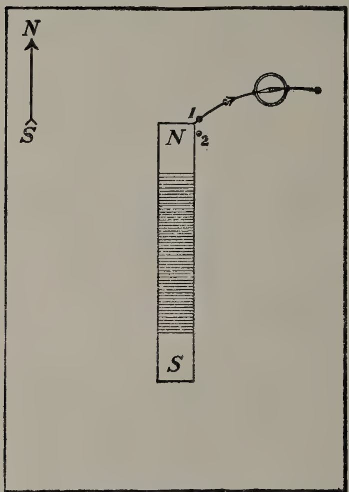


FIG. 106. Plotting the field of a bar-magnet.

Place a jeweller's compass (with needle about 1 cm. long) at the north-east point of the magnet—at the point marked *1* in the figure—and with a pencil put two dots on the paper close to the compass case, such that the line joining them is directly under the needle. Then place the compass so that the *S*-end of the needle is over the farther-out dot, and make another dot at the *N*-end again. Continue obtaining dots in this way until the compass arrives at the edge of the paper or back at the magnet again. Now draw a curve passing through all the dots and mark arrow-heads on it to indicate the direction in which the *N*-pole of the compass pointed.

Then start at the point marked *2* in the diagram and obtain another curve in the same way. Continue this, beginning at other points on the magnet, until you have made the com-

plete circuit of the magnet. In this way curves are obtained running from every portion of the magnet. These curves indicate the direction of the lines of force.

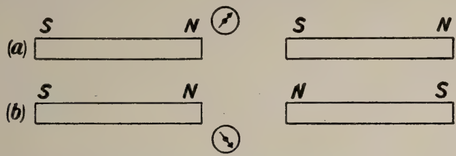


FIG. 107.—Plotting the field of force between the magnets —(*a*) unlike poles, (*b*) like poles.

Next, place two bar-magnets so that their axes are in the same straight line, the *S*-pole of one being about four inches from the *N*-pole of the other (*a*, Fig. 107) and plot the field of force in the same way, paying particular attention to the region between the two unlike poles.

Repeat with the magnets placed so that two like poles face one another (*b*, Fig. 107.)

Experiment 99.—To study magnetic fields of force by using iron filings. (TEXT-BOOK, § 400.)

APPARATUS:—Two bar-magnets, a horse-shoe magnet, iron filings, sheet of cardboard.

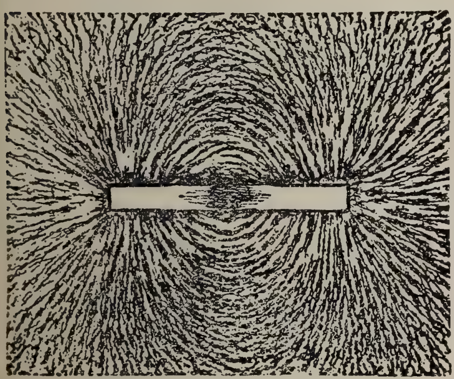


FIG. 108.—Field of force of a bar-magnet.

Method.—Lay the piece of cardboard over the bar-magnet and scatter iron filings evenly, but not too thickly, over it. This may be done by means of a pepper-box or a bag of muslin held about a foot above the magnet. Tap the card with a pencil to assist the filings to arrange themselves (Fig. 108.) The card should be kept level by small pieces of wood.

In addition to the above, obtain figures with the filings in the following cases :—(*a*) Two bar-magnets with their axes in the same line, and having unlike poles facing each other. (*b*) The same, with like poles facing each other. (*c*) Stand a magnet on end and rest the cardboard in a horizontal plane on a pole. (*d*) A horse-shoe magnet.

Sketch in your note-book the figures shown by the lines of force in the above five cases.

NOTE.—Magnets must be handled carefully. Jarring them or touching like poles together weakens the magnetism. They should be kept well apart, with the *N*-poles pointing downwards; or arranged in pairs with opposite poles near together, and a soft-iron keeper across them.

Experiment 100.—To study the nature and properties of magnets. (TEXT-BOOK, §§ 398, 404, 406.)

APPARATUS:—Knitting-needle, file, bar-magnet, compass, iron filings, pieces of iron rod, glass tube fitted with corks, Bunsen burner.

Method.—1. *Effect of breaking a magnet.* With a three-cornered file score a knitting-needle at points approximately $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, $\frac{1}{16}$ of its length from one end. Then magnetize it by stroking it with one pole of a bar-magnet. Test its polarity by approaching each end to a compass needle. Mark the *N*-pole by melted paraffin wax, or by sticking a bit of paper to it with soft wax.

Pour some iron filings on a paper, and immerse the needle in them. Then lift it up and note to what part of it the filings cling. Are there any at the middle? Do you think the needle is magnetized at the middle?

Now break the needle in half, and test the freshly-broken ends with the compass needle, and also with the filings. Was the needle magnetized at the middle? Break one of the pieces in half again, and repeat the tests. If possible, break again and test.

Next, fill a glass tube about $\frac{1}{2}$ inch in diameter and 6 inches long with iron filings, stopping each end with a cork. Test this with the compass. Does the tube show any polarity?

Now stroke it from end to end, always in the same direction, with one pole of a magnet, and test again with the compass. Does it exhibit polarity now? Shake it up thoroughly and test again.

State fully what you have observed. What conclusion would you naturally reach as to the magnetic properties of the molecules of iron?

2. *Effect of heating a magnet.* Dip a piece of magnetized knitting-needle in iron filings. Then heat it to redness in a Bunsen flame and try with the filings again. Record the result. What effect has heating upon a magnet?

3. *Magnetization by Induction.* Hold a piece of soft-iron rod, about ½ inch in diameter and 6 inches long, near some iron filings. Does it attract them?

Next, hold one end of it near one pole of a strong magnet and approach the other end to the filings. Do they adhere? Remove the magnet. Does this affect the filings? Carefully test with a compass if the iron rod shows any polarity at all. If it does, hold it in an E and W direction and strike it several times. Then test again. What do you conclude as to the condition of a piece of iron when it is placed in a magnetic field?

Take a rod of soft iron 1½ or 2 feet long (a poker will do), and, holding it in an E and W direction, test with the compass whether it exhibits polarity. (Test for repulsion.) If it does, hold it pointing E and W and strike it sharply several times. Test again.

Then hold it in an almost vertical direction, with the upper end tilted a little to the south, and strike it with a hammer several times. Now test for polarity; in doing so, hold the rod in a vertical direction. Does it show polarity? Which end is the N-pole? Can you account for its magnetization? Repeat, reversing the ends of the rod.

Can you draw any conclusion as to the probable arrangement of the molecules of iron in a magnetized and in an unmagnetized rod?

***Experiment 101.—To study electrical attraction and repulsion.** (TEXT-BOOK, §§ 414-416.)

APPARATUS:—Rods of glass and sealing-wax (or ebonite); pith-ball, suspended by a silk fibre; pieces of silk (best quality) and flannel; wire stirrup.

Method.—Bring the glass rod near some bits of thin paper or saw-dust or bran. Do you observe any action? Try with the sealing-wax. What result?

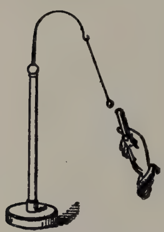


FIG. 109.—A pith-ball on the end of a silk thread drawn towards the electrified rod.

Rub the glass with silk and try again. Then rub the sealing-wax with flannel and try it. What results in these two cases?

What is an *electrified* body?

Rub the glass and bring it near a pith-ball. (Fig. 109.) What action? Allow the pith-ball to touch the glass. What results? Bring the rod near it again. What effect?

Rub the pith-ball between the fingers and also rub the hand over the sealing-wax. Bring the sealing-wax near the pith-ball. Any effect? Rub the sealing-wax with flannel and bring it near the pith-ball. What result? Let the pith-ball touch the wax. Does it remain in contact? Bring the wax near it again. What action do you observe? Next rub the glass with silk and bring it near the pith-ball. What effect?

Next, rub the glass rod with silk and suspend it in a stirrup supported by a silk thread. Then rub the sealing wax with flannel and bring it near the glass rod. What action do you observe?

State the law of electrical attraction and repulsion.

Experiment 102.—To study the action of an electroscope. (TEXT-BOOK, §§ 419-422, 435.)

APPARATUS:—Simple electroscope (Fig. 110); ebonite rod; sealing-wax; glass rod; piece of silk; sheets of mica, ebonite and glass; two metal plates about 4 in. square mounted on wooden blocks.

Method.—1. *To charge the electroscope by contact.*

FIG. 110.—A simple electroscope.

Rub the ebonite on the coat-sleeve and bring it up to the electroscope and touch the plate with it. What happens to the leaves, (*a*) when the ebonite is being brought up to the electroscope, (*b*) when it is in contact with the plate, (*c*) when it is removed? What kind of charge is on the ebonite and what kind is on the electroscope after it is charged?

2. *To charge the electroscope by induction.*

Touch the electroscope with the hand, to remove any charge it may have. Rub the ebonite again and bring it *near* the plate. What happens to the leaves? What charge is now on the plate and on the leaves? Touch the plate with the finger. What happens to the leaves? Remove the finger and take away the rod. What charge is on the leaves now?

3. *To test the charge on rubbed sealing-wax and rubbed glass.*

Place a known charge on the electroscope by using the ebonite rod. (This can be done most easily by induction.) Rub the sealing-wax on the sleeve and bring it towards the plate slowly. Do the leaves diverge still farther or fall? What charge must the sealing-wax have? Rub the glass (previously dried by heating) on the silk and test its charge in the same way.

4. *To study the principle of the condenser.*

Connect the plate of the electroscope by a wire to one of

the metal plates and stand the latter on two pieces of sealing-wax or paraffin to insulate it from the table (Fig. 111). Join a wire to the other plate and connect it to a gas or water tap or keep the hand in contact with it. Place a charge on the electroscope and plate connected to it and then bring the earth-connected plate slowly up until only a few millimetres from the other. What happens to the leaves? Remove the plate; what happens? Explain the action.

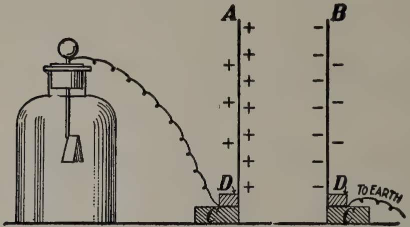


FIG. 111.—Arrangement to illustrate the action of a condenser. Metal plates A, B, are attached to wooden blocks D, D, resting on paraffin blocks C, C.

Bring up the earth-connected plate again and note the position of the leaves. Insert the sheet of mica between the plates. What effect has this on the leaves? Remove the mica and insert in turn the ebonite and the glass (previously dried by heating). Is the effect more or less pronounced? On what does the capacity of a condenser depend?

Use the Electron Theory to explain what happened in each of the above experiments.

Experiment 103.—To study the magnetic effect of an electric current. (TEXT-BOOK, § 447.)

APPARATUS:—In this experiment we require a Daniell or other voltaic cell, a compass needle and connecting wires.

The copper (or carbon) plate of the cell is said to be *positive* and the zinc *negative*. When these are joined by a wire the electric current is considered to flow from the positive terminal, through the wire, to the negative terminal of the cell.

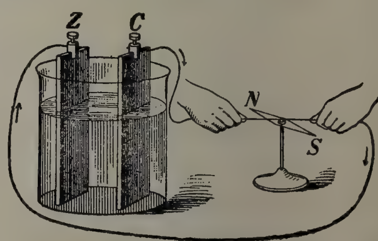


FIG. 112.—Showing that the electric current exerts an action on a magnetic needle.

Method.—Connect one end of the wire to the positive terminal of the cell, stretch the middle part of the wire

straight and hold it over the compass needle so that the current will pass from N to S when the other end of the wire is joined to the negative terminal (Fig. 112). Complete the circuit long enough to note the effect on the needle. Then disconnect and record the direction in which the N-pole was deflected, *i.e.*, whether to east or to west.

Next, hold the wire so that the current will pass from S to N above the needle and again note the direction of the deflection.

Now hold the wire under the needle and record the deflection (1) when the current flows from N to S, (2) when it flows from S to N.

Make a loop in the wire and hold it so that one portion is above and the other below the needle. Record the deflection (1) when the current goes above the needle from N to S, (2) when it goes from N to S below the needle. Is there any difference in the amount of the deflection as compared with that obtained without looping the wire?

Place the compass on the edge of the table, or on a book standing on end, and stretch the wire in a vertical position near the N-pole of the needle. Record the effect (*i.e.*, the deflection) when the current is flowing down and also when flowing up.

Record your results as follows:—

Current Flowing	Direction of Deflection of N-pole
From N to S above........................	
From S to N above........................	
From N to S below........................	
From S to N below........................	
From N to S above and S to N below..........	
From S to N above and N to S below..........	
Downwards in a vertical line..................	
Upwards in a vertical line......................	

State the law connecting the direction of the current and the behaviour of the needle. (Text-Book, § 447.)

It is evident then that by observing the deflection of a needle held near a wire we can determine the direction in which the current is flowing. To test this, let one student change the connections of the battery, covering it up so that the terminals cannot be seen, and let another student determine in which direction the current flows.

Do you know any electrical instruments in which the action just investigated is applied?

Next, explore more fully the field about a vertical wire carrying a current. Pass the wire through the centre of a piece of cardboard held horizontally. While the current is passing place a small compass needle near the wire. Allow the needle to come to rest; then remove it and mark on the cardboard a short straight line with an arrow-head on it to indicate the direction in which the *N*-pole pointed.

Place the needle in various positions around the wire at regular intervals,in each position drawing a line to indicate the direction of the *N*-pole. If the work is done carefully it will be seen that the lines of force about the current are circles.

Experiment 104.—To study a single-fluid voltaic cell. (Text-Book, §§ 442, 447, 449.)

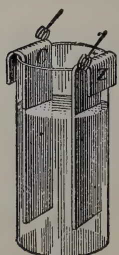


Fig. 113.—A simple voltaic cell.

Apparatus:—To construct a simple cell we require a glass vessel, strips of copper and zinc with copper wire soldered or otherwise securely fastened to them, and some clean diluted sulphuric acid (1 c.c. of strong acid to 20 c.c. of water.) (In mixing, pour the acid slowly into the water, stirring continually.)

For testing the cell use a galvanoscope, which may consist simply of several turns of insulated wire wound on a frame over a compass needle (Fig. 114). When working with this instrument place it so that the coils of wire are parallel to the needle.

Method.—Fill the glass jar with the dilute acid to within about 2 cm. from the top (Fig. 113). Rub the copper strip with sandpaper until that part which will be immersed in the acid is clear and bright. Place the zinc strip in the jar, and observe its surface for a few minutes. What change takes place in the appearance of its surface? What is the gas which is given off? Place the copper strip also in the acid, holding it parallel to the zinc and near it, but not touching it. Does the presence of the copper in any way affect the phenomena just observed? Does any change take place in the appearance of the surface of the copper? Next, join the two copper wires to the terminals of the galvanoscope. Observe and record what happens at each strip. Note also the behaviour of the galvanoscope needle. Tap the instrument gently to help the needle to overcome the friction on its bearing.

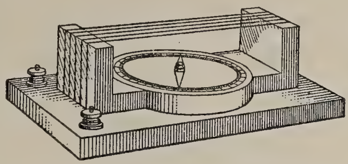


FIG. 114.—To make this galvanoscope the wire is wound several times about the frame and the ends are fastened to the binding-posts.

Next, disconnect the wires from the galvanoscope, remove the zinc strip from the cell and amalgamate its surface by dipping it for a moment in mercury and then rubbing it over with a tooth-brush or a cloth. (It will be convenient simply to substitute an already amalgamated plate for the other one.) Shake or wipe off all superfluous mercury and weigh carefully, but protect the balance-pan with a glass dish. Replace the zinc in the cell. Be sure that no mercury touches the copper plate at any time. Observe and record the action now taking place at the surface of the strips.

Again connect the strips to the galvanoscope, and observe the strips and the needle as before. Take observations of the deflection of the needle every minute for 5 minutes.

If there is no decided change in the deflection during the 5 minutes, take the copper strip out, rinse it and scour it with sandpaper. If the acid is in proper condition the strip will look bright when removed from the acid. Replace in the acid and observe for 5 minutes as before. After allowing the action to continue for about 10 minutes, remove the zinc, rinse off the acid and carefully weigh again. Has there been any chemical action?

Explain what is meant by *local action* and *polarization* How can these be prevented in cells?

Experiment 105.—To arrange a number of metals in an electromotive series. (TEXT-BOOK, § 464.)

APPARATUS:—Galvanoscope or (preferably) a 0-3 volt voltmeter (Fig. 115); strips of zinc, copper, iron, lead, tin, aluminium, carbon, dilute sulphuric acid, tumbler or other glass vessel, connecting wires.

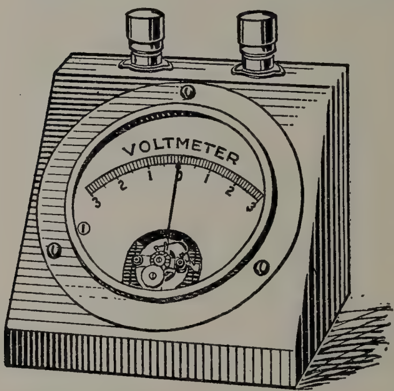


FIG. 115.—A convenient voltmeter.

Method.—Place the zinc and copper plates in the sulphuric acid solution and connect to the voltmeter or galvanoscope (Fig. 116). (If the plates are not provided with terminals, a good enough contact can be made by pressing the wires firmly against the plates.) Note the direction and amount of the deflection of the needle.

Next, replace the copper plate in succession by each of the other plates. Note carefully the direction and amount of the deflection in each case, and from the direction of the deflection determine which plate is positive and which negative in each combination.

Remove the zinc plate and test the different cells which can be made by taking copper in combination with the other metals, and so continue until every possible arrangement has been tested.

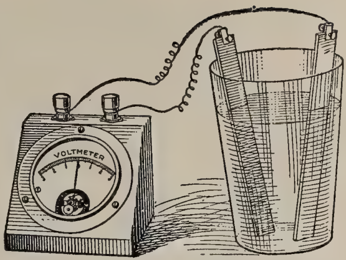


FIG. 116.—Testing which plate is positive with respect to the other.

Record results as follows:—

CELL	+PLATE	−PLATE	DEFLECTION
Zinc-copper	Copper	Zinc	
Zinc-iron			
Zinc-lead			
Zinc-tin			
Zinc-aluminium			
Zinc-carbon			
Copper-iron			
etc.			

Arrange the plates tested in a potential or electromotive series. (TEXT-BOOK, § 464.)

Which arrangement gives the highest E. M. F.? What plates are used in a dry cell?

Experiment 106.—To study a two-fluid voltaic cell. (TEXT-BOOK, § 470.)

APPARATUS:—Material for a Daniell cell (glass vessel, porous pot, copper and zinc plates, copper sulphate and dilute sulphuric acid solutions); galvanoscope.

Method.—Put the zinc plate in the porous cup, and set it and the copper plate in the outer jar. Pour into the porous cup dilute sulphuric acid (1 c.c. of acid to 10 c.c. of water), and into the outer vessel pour a saturated solution of copper

sulphate (Fig. 117). Let it stand for a short time in order that the liquid may pass through the porous cup. Then join the plates to the galvanoscope and note the reading.

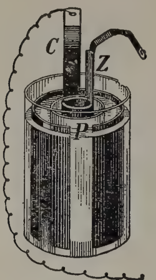


FIG. 117.—A form of Daniell cell.

Remove the copper plate, let it drip for half-a-minute (but do not wipe it) and then weigh it. Protect the balance-pan with a glass dish. Replace it in the cell. Wipe the liquid from the glass dish on the balance-pan. Lift the zinc from the acid, let it drip for half-a-minute and weigh it carefully. Put it back in the cell and wipe the liquid from the glass on the balance-pan.

Again join up to the galvanoscope, recording the time when you do this. Tap the galvanoscope slightly to assist the needle to reach its position of equilibrium, and when it has come to rest record its reading.

Record the position of the needle every five minutes for twenty minutes. Then disconnect from the galvanoscope, recording the time you do so. Weigh the metal plates again precisely as before. Calculate the amount each plate has lost or gained per minute of the time when the cell was in operation.

The zinc plate should be amalgamated, but not immediately before the experiment. The mercury might drip off during the exercise, making the weighing of the zinc useless.

Experiment 107.—To study the electrolysis of water. (TEXT-BOOK, § 453.)

APPARATUS:—Apparatus constructed specially for this experiment may be used. That illustrated in Fig. 118 can be made by cutting off the bottom of a wide-mouthed bottle and then inserting platinum electrodes through the cork. Pour melted paraffin over the cork to insure that it is water-tight and to protect it from the acid.

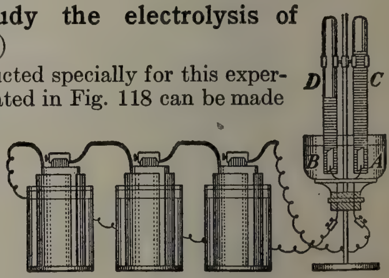


FIG. 118.—A simple form of apparatus for electrolysis of water.

Nearly fill the vessel with dilute sulphuric acid (1 c.c. of acid

to 40 c.c. of water), then fill the test-tubes with the same liquid and invert them over the platinum electrodes.

Method.—Join the apparatus to 2 or 3 dry or 3 or more Daniell cells, or any other suitable source of direct current, and allow the current to run for some minutes. Trace the direction of the current. The terminal by which it enters the liquid is called the *anode*, the one by which it leaves is the *cathode*. Compare the volume of gas liberated at the cathode with that liberated at the anode. The former is hydrogen, the latter oxygen.

When the hydrogen tube is full of gas, lift it out and immediately bring a lighted match near its mouth. The gas puffs out, burning with a pale blue flame, a test for hydrogen. When the oxygen tube is full, lift it and plunge a glowing splinter into it. The splinter bursts into flame, a test for oxygen.

Experiment 108.—To study electroplating. (TEXT-BOOK, § 457.)

APPARATUS:—Tumbler, copper sulphate, copper plate, strip of iron, sandpaper, storage cell (or 2 or 3 dry or Daniell cells), rheostat.

Method.—Fill the tumbler with a solution of copper sulphate (100 grams of copper sulphate to 500 c.c. water). For anode use the copper plate and for cathode the strip of iron (or a brass object). The object should be carefully cleaned by rubbing it with sandpaper. This usually is sufficient, but if necessary it should be dipped in a hot solution of caustic soda, rinsed in water and then dipped in dilute nitric acid.

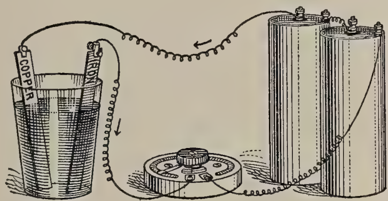


FIG. 119.—Electroplating with copper.

Connect the battery, rheostat and electrolytic cell as shown in (Fig. 119). By turning the knob of the rheostat the strength of the current can be regulated. It should not be too great. Let the current run for a minute. Lift the iron out of the

solution and examine it. Record any change. Then let it run for 15 minutes. The electrodes may be lifted out from time to time for examination. Record any changes observed.

If possible, explain the chemical action which has taken place.

NOTE.—It will be observed that when a strip of iron is placed in a solution of copper sulphate it becomes coated with a *thin* layer of copper without the action of an electric current. This is a purely chemical action. To obtain a thick layer an electric current must be used.

Experiment 109.—To measure the strength of a current by means of a copper voltameter. (TEXT-BOOK, § 456.)

APPARATUS:—Copper voltameter, (Fig. 120). (Two pieces of sheet copper in a tumbler will serve); saturated solution of copper sulphate; storage battery or other suitable source of direct current; resistance; connecting wires. (See notes below.)

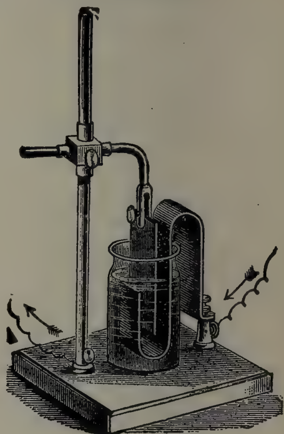


FIG. 120.—A copper voltameter.

Method.—Clean the cathode with sandpaper or emery cloth and carefully weigh it. Nearly fill the glass vessel with the solution and insert the anode and cathode so that they are the same distance apart at all points. Connect the source to the resistance and voltameter as in Fig. 121 and pass the current through the solution for 15 or 20 minutes, which time should be carefully observed. (The current should not exceed 1 ampere for each 50 sq. cm. of cathode surface.)

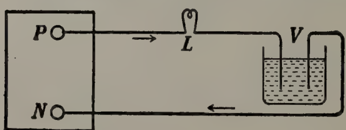


FIG. 121.—Connections when using a voltameter. P, N are the terminals of the source of electricity, L a resistance and V the voltameter.

Remove the cathode, wash it under the tap without rubbing, dry it carefully by holding it in the hand in the heated air over a Bunsen burner and weigh it again.

Record your results and calculate the current strength as in the following example.

Initial weight of cathode	50.342 gm.
Final weight of cathode..........	51.080 "
Time..........................	15 min.

$$\text{Current} \ldots\ldots = \frac{.738}{900 \times 0.000328} = 2.5 \text{ amperes}$$

NOTES.—1. A 32 c.p. carbon filament lamp may be used with 110-volt direct current. The current in this case will be about 1 ampere. If a storage battery is used a 10-ohm variable resistance, such as is used in radio sets, or an automobile headlight lamp will be found suitable.

2. If an ammeter is available it may be inserted in *series* with the resistance and the voltameter to check the result obtained by the voltameter method. *Be sure that you have the resistance in series with the ammeter.*

Experiment 110.—To construct an electroltytic rectifier. (TEXT-BOOK, § 460.)

APPARATUS:—Plates of lead and aluminium, jar containing saturated solution of borax, bank of three 32 c.p. carbon lamps in parallel, copper voltameter, source of alternating current.

Method.—Clean and weigh both plates of the voltameter carefully. Connect apparatus as in Fig. 122. *TT* are the alternating current terminals, *R* is the rectifier consisting of the lead and aluminium plates in the borax solution, *L* is the bank of lamps and *B* is the copper voltameter.

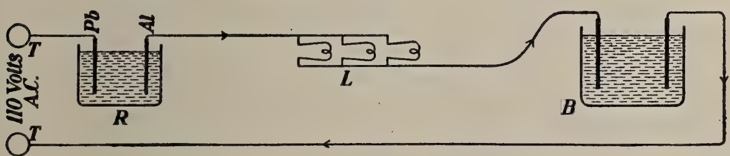


FIG. 122.—An electrolytic rectifier.

Let the current run for 15 or 20 minutes, which time should be noted carefully. Remove the plates, remembering which one was connected to the bank of lamps, wash and dry carefully and weigh them again.

Which plate has gained in weight? Did the rectified current flow through the rectifier from lead to aluminium or the reverse?

Calculate the strength of the rectified current as in Experiment 109.

Experiment 111.—To construct a simple storage cell. (Text-Book, §§ 471, 472.)

Apparatus:—Two lead plates, jar containing dilute sulphuric acid, source of direct current, suitable rheostat, connecting wires, voltmeter (or galvanoscope), electric bell.

Method.—Clean the lead plates with sandpaper and place them in the acid. Connect the apparatus as in Fig. 123, adjusting the lamp or other rheostat so that about 1 ampere flows through the lead cell. (If direct current is not available, a rectifier may be used with alternating current.) Observe the action at the plates while the current is flowing, noting any change in colour and also at which plate the greater amount of gas is liberated.

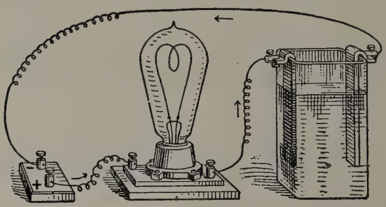


Fig. 123.—Arrangement for producing a storage cell.

After the current has flowed for about five minutes, disconnect the lead cell and connect it to the voltmeter (or galvanoscope). Note the reading, and from the direction of the deflection, state whether the anode or the cathode has become the positive plate of the storage cell. See if you can ring an electric bell with the cell. Does it operate the bell long?

Next replace the cell in the charging circuit and charge for 15 minutes. Disconnect and test the voltage again. Is there any change? Does the cell operate the bell for a longer time? How are commercial storage cells constructed so as to have

great capacity? Examine a commercial cell* if one is available.

State in simple terms the chemical action that occurs when the cell is being charged and when it is being used to furnish current.

Experiment 112.—To construct and study an electromagnet. (TEXT-BOOK, §§ 479-481.)

APPARATUS:—Insulated wire, iron rods, battery, compass, tacks.

Method.—Wind insulated copper wire (No. 22 or 24) in a close spiral about two soft iron rods about 10 cm. long and 1 cm. in diameter. Leave 15 or 20 cm. of wire over at each end.

FIG. 124.—Indicate by an arrow-head on the curve the direction of the current producing the pole.

Join the ends of a coil to a battery of one or more cells, and see how many tacks the iron will pick up. Stop the current; how many tacks will it lift now?

Start the current again, and with a compass test the nature of each pole. Then reverse the current and test the poles again. Look at the *N*-pole and trace in what direction the current is flowing. Do the same for the *S*-pole. Record the directions as in Fig. 124. Put an arrow-head on the curve above the *N* and the *S* to show in what direction the flow is in each case.

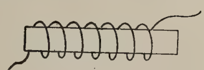


FIG. 125.—Mark on the diagram the direction of the current flow and the resulting polarity.

Next, join the ends of the two coils so that the two iron rods will act like a horse-shoe magnet. Draw a diagram (as in Fig. 125, but for the two magnets) and mark on it the direction of the current flow and the resulting polarity of the iron. Test the attracting power of this double-magnet with small tacks.

Name any electrical instruments in which electromagnets are used.

*Small storage cells (capacity about 2 ampere-hours) are now constructed to serve as "B" batteries for radio receiving sets. These cells can be used in the laboratory in many experiments, instead of primary cells. The cost is about twice that of a dry cell.

Experiment 113.—To study the construction and action of an electric bell. (Text-Book, § 488.)

Apparatus:—Electric bell, battery, compass needle, connecting wires.

Method.—Connect the electric bell and push-button with a dry cell (or other battery), and examine the behaviour of the hammer as the circuit is closed. Trace the current through the bell.

With a compass determine the condition of the poles of the electromagnet as the hammer moves towards the bell and as it recedes from it.

Explain what causes the hammer to go forward towards the gong and then to leave it.

Examine carefully the construction of the bell.

Draw a diagram, including the bell, the battery and the button, which will clearly show its action. Put arrows on it to show the course of the current.

***Experiment 114.—To study the construction and action of a telegraph sounder and key.** (Text-Book, §§ 483-487.)

Apparatus:—Telegraph key, sounder, battery, connecting wires.

Method.—Put together the parts of a simple telegraph key, sounder, and battery.

Depress the key and watch the effect. Trace the current from one pole of the battery through the circuit to the other pole.

Draw a diagram and mark on it the course of the current throughout the circuit.

Experiment 115.—To study the use of a voltmeter and an ammeter. (Text-Book, §§ 492, 493.)

Apparatus:—Voltmeter, ammeter, two Daniell cells and a dry cell, fuse wire, rheostat.

Method.—Connect the ammeter, rheostat, and dry cell in series as shown in Fig. 126, using the fuse wire to make one of the connections to the ammeter. Before completing the circuit make sure that the rheostat is set so that the current flowing through the ammeter will not exceed the range of the instrument*. The fuse is an extra safety precaution after the *greatest possible care* has been taken. Connect the voltmeter directly to the cell terminals and *make sure that it is a voltmeter* before connecting it. Adjust the rheostat until the ammeter registers two or three amperes.

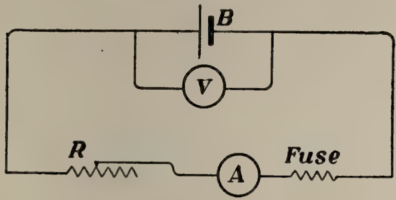


FIG. 126.—Arrangement of circuit. *A*, ammeter; *V*, voltmeter; *B*, battery; *R*, rheostat.

Observe the readings on the two instruments. Let them remain connected for 5 or 7 minutes and note the readings on the instruments every minute. What causes the change in the current? Is it due to decreasing electromotive force or increasing resistance?

Now substitute a Daniell cell for the dry cell and make similar observations for 5 minutes. How does the Daniell cell compare with the dry cell as to E.M.F., resistance, strength of current, constancy of current?

Join two Daniell cells in series and observe the E.M.F., and current strength.

Then join the two cells "in parallel" and repeat the observations. Compare the E.M.F. and current strength with the values of these quantities in the last case.

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*A low range ammeter must *never* be joined directly to a storage cell or a dry cell in good condition. A new dry cell short-circuited will furnish a current of twenty to thirty amperes and a storage cell much more. This current will absolutely ruin a low range instrument.

Experiment 116.—To study the currents induced by a magnet. (TEXT-BOOK, §§ 495, 496.)

APPARATUS:—For this experiment we require a fairly sensitive galvanometer or low range voltmeter, a spool of wire with many turns on it (800 or more), and a bar-magnet. The spool must be hollow, such that the magnet may be thrust through it, and be wound in such a way that the direction of a current through it may be traced.

Method.—First find the relation between the direction of the current through the galvanometer and the direction in which its moving coil is thereby made to swing. To do this join two wires to the galvanometer; wind the end of one of these about a piece of zinc, and then dip the zinc and also the bare end of the other wire into a vessel containing water with a drop of sulphuric acid or a grain of common salt in it. This will form a weak cell, strong enough, however, to affect the galvanometer. If a voltmeter is used it can be connected directly to a dry cell (Fig. 127).

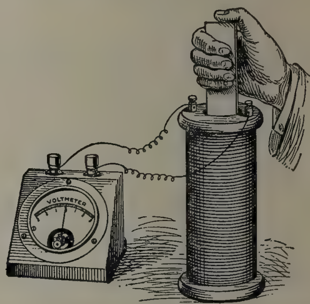


FIG. 127.—Arrangement for studying the production of induced currents. The galvanometer should be far enough from the coil that it will not be affected directly by the magnet.

Observe at which terminal the current enters the galvanometer and the resulting direction—to right or to left—of the pointer. Record this in your note-book. Having done this it will be possible, by observing the direction of the throw of the galvanometer, to say in which direction the current flows.

1. Now discard the cell and join the galvanometer wires to the ends of the spool of wire. Thrust the *N*-pole of the bar magnet into the spool of wire, at the same time watching carefully the galvanometer. Was a current produced? How

long did it last? Such a current is said to be produced by *induction*. (If more convenient keep the magnet fixed and slip the spool over it.)

In what direction did the current pass through the galvanometer? Trace the current through the spool.

When a current traverses a coil, the coil becomes an electromagnet. Having determined the direction in which the current passed, find out which face of the spool was made a N-pole and which a S-pole. Thus see whether it was a N-pole or a S-pole which was produced as the N-pole of the magnet approached it. If it was a N-pole, it would repel the magnet and thus tend to stop its motion.

Repeat this experiment, thrusting the N-pole in with different speeds. Does the rapidity of the motion make any difference in the current induced?

2. Next, try similar experiments with a S-pole. In what direction is the current induced when the S-pole enters the coil? Which is now the N-pole of the coil? Does the coil repel or attract the S-pole of the magnet as it approaches?

3. Slowly push the N-pole of the magnet into the coil and let it rest there. Allow the coil of the galvanometer to come to rest. Then quickly withdraw the magnet. In what direction is the induced current? Does it oppose or assist the motion of the magnet?

4. Perform similar experiments, using the S-pole of the magnet.

State a rule as to the direction of the induced current for any case of relative motion between a magnet and a coil of wire. (Lenz's Law, TEXT-BOOK, § 496.)

Experiment 117.—To study the currents induced in one coil by currents in another. (TEXT-BOOK, §§ 497, 498.)

APPARATUS:—One coil, which is called the *secondary*, should have many turns of wire and should be joined to a galvanometer or low range voltmeter. The other, known as the *primary*, should be small enough to slip within the former. One or two dry cells, a push-button. (Fig. 128.)

Method.—1. Join the primary coil in series with a push-button and a battery of one or two dry cells. By using a compass needle or by noting the way the coil is wound, determine which end of the coil becomes the *N*-pole and which the *S*-pole when the button is pressed. Press the button, insert the primary in the secondary coil and note the way the induced current flows; remove the primary and again note the direction of the induced current.

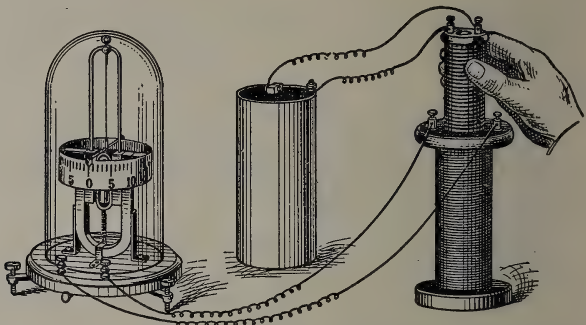


FIG. 128.—Apparatus for showing that an electromagnet acts like a permanent magnet in inducing currents in a coil. In place of the galvanometer a low range voltmeter may be used, and a push-button may be inserted in the primary circuit.

Does the induced current flow in the same direction as the primary current or in the opposite direction when the primary coil is inserted? How does it flow when the primary coil is withdrawn? Is this according to Lenz's Law?

2. Next, place the primary coil inside the secondary and press the push-button. Which way does the induced current flow? Break the circuit and again observe the direction of the induced current. When the primary circuit is completed does the induced current flow in the same direction as the primary current or in the opposite direction? How does it flow when the current in the primary is broken?

Reverse the connections to the primary coil and try these experiments again.

3. Place a soft iron rod through the primary and repeat (2). Do you observe any difference in the results?

4. Remove the primary from within the secondary, but keep both on the iron rod. Repeat (2). Do you observe any difference from (3)?

State a Law governing the direction of the current in the secondary coil as compared with the direction of the current of the primary. (TEXT-BOOK, § 498.)

Experiment 118.—To study the construction and action of an electric dynamo and motor. (TEXT-BOOK, §§ 503-511.)

APPARATUS:—St. Louis motor (Fig. 129), complete with permanent magnets and electromagnet and both A.C. and D.C. armatures; two dry cells or one storage cell; galvanometer or low range voltmeter.

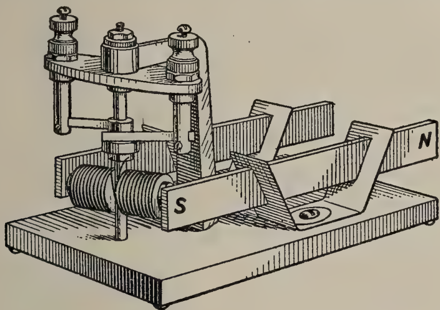


FIG. 129.—A St. Louis motor.

Method.—1. *Magneto.* Insert the A.C. armature and use the permanent magnets to supply the field, placing them so that the armature nearly touches them. Connect the brushes to the galvanometer and note carefully the action of the galvanometer as the armature is rotated slowly. In what position is the coil when the induced current changes direction? Why does it change direction? Rotate the armature more rapidly. Is there any change in the induced current?

2. *D.C. Generator.* Substitute the D.C. for the A.C. armature and adjust the brushes so that they rest on the insulation between the commutator sectors, at which time the coil is in the position where the current reversed in (1). Rotate the armature in a clockwise direction. Why is the current

now uni-directional or direct? Rotate the armature in the opposite direction. Is the direction of the current the same in both cases? Note the effect of increasing the speed of rotation. Alter the strength of the field by moving the bar-magnets to different distances from the armature while it is revolved at uniform speed. What is the effect on the E.M.F.? On what factors does the E.M.F. of a generator depend?

3. *D.C. Motor, using permanent magnets to produce field.* Substitute the storage cell or two dry cells in series for the galvanometer and note the direction in which the armature rotates. Reverse the connections of the brushes and note again the direction of rotation. Add another cell to increase the current through the armature. What is the effect on the speed of rotation? Weaken the field by moving the bar-magnets farther away from the armature. Does the speed change?

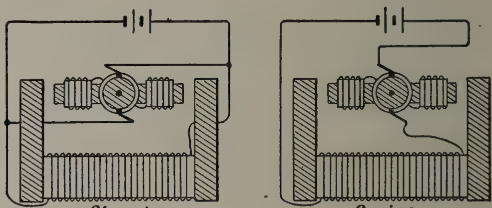


FIG. 130.—Series-wound and shunt-wound motor.

4. *Series-wound Motor.* (Fig. 130.) Use the electromagnet to produce the field instead of the bar-magnets. Connect it in series with the armature and battery and note the direction of rotation. Reverse the battery connections. Does the direction of rotation change? Explain. How could you reverse the direction of rotation of the motor? Try your method.

5. *Shunt-wound motor.* (Fig. 130.) Connect the armature and field coil in shunt and note the direction of rotation when the battery is connected to the brushes. Reverse the battery connections. What happens? See if you can work out a method for reversing the motor.

***Experiment 119.—To study the construction and action of the telephone.** (TEXT-BOOK, § 515.)

APPARATUS:—Two telephone receivers, two microphones, two telephone transformers, two dry or storage cells, ammeter, connecting wires.

Method.—Join the two receivers together by wires several yards long (from one room to another). Hold one to your ear and see if you can hear words which a fellow-student speaks into the other.

Remove the cap and diaphragm from one receiver and trace the circuit through it. (Be careful not to break the fine wires in the receiver.) What effect has speaking into it? How is this transmitted to the other end? Draw a diagram to show the connections.

Next, join a dry cell in series with a microphone, the ammeter and the primary of one of the telephone transformers. Note the ammeter reading and then blow into the microphone or speak into it. What happens to the current as registered by the ammeter?

Connect the secondary of the transformer in series with the two receivers and the secondary of the other transformer as shown in Fig. 131. Connect the primary of the second

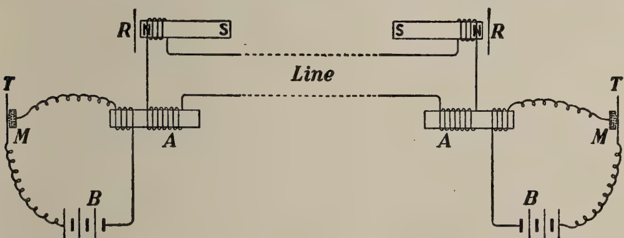


FIG. 131.—Diagram of telephone circuit. *T*, transmitter; *M*, carbon microphone; *B*, battery; *A*, step-up transformer; *R*, receiver.

transformer to the other microphone and dry cell. You have now two stations and should be able to carry on a conversation with your companion. (If the distances are short, it is more satisfactory to test the instruments by blowing into the microphones.)

Trace the transformations of energy, beginning with the sound-waves which cause the transmitter diaphragm to vibrate, and ending with the sound-waves received by the listener's ear.

Experiment 120.—To measure resistance by using a voltmeter and an ammeter. (TEXT-BOOK, §§ 527, 531.)

APPARATUS:—Unknown resistance (not to exceed 20 ohms), low range ammeter and voltmeter, rheostat, two dry or storage cells, heavy connecting wires.*

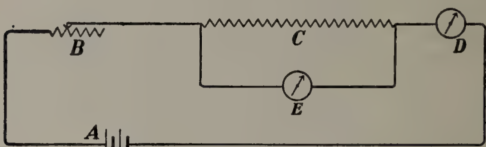


FIG. 132.—Measuring the resistance of the wire C by means of a voltmeter E and an ammeter D.

Method.—Connect the apparatus as shown in Fig. 132. A is the battery, B the rheostat, C the unknown resistance, D the ammeter and E the voltmeter.

Read the ammeter and voltmeter carefully and then move the slider in B to a new position and repeat the readings. Obtain at least five sets of results, making sure that the temperature of the wire does not rise by any appreciable amount.

Tabulate results as follows:—

VOLTMETER READING	AMMETER READING	$R = \frac{\text{VOLTS}}{\text{AMPERES}}$
	AVERAGE	

If possible, use a wire whose length is known, and measure its diameter with a micrometer gauge. By consulting a table of resistance of wire of different sizes its resistance can be calculated (page 156). Compare this with your measured result.

*Use a piece of fuse wire to make one of the connections to the ammeter.

Experiment 121.—To compare resistances by the method of substitution. (Text-Book, § 531.)

Apparatus:—Wires, ammeter, commutator (which however may be dispensed with), Daniell or storage battery. The wires whose resistances are to be compared should, preferably, be wound on spools (Fig. 133.) Use two pieces of German silver wire, No. 30, 10 feet long and one piece of No. 24, 40 feet long. (German silver is a compound of copper, zinc and nickel, and it is very desirable that the larger wire should be of the same composition as that of the smaller.) Double the wire and wind it on a spool which has been soaked in hot paraffin, being careful not to have the two strands of the wire touching. After winding on the spool dip (not soak) it in paraffin again.

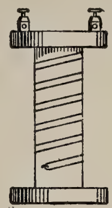


Fig. 133.—A spool with wire wound on it for measuring resistance.

Method.—Join a Daniell cell *B*, the wire *W*, the commutator *C*, and the ammeter *G* as shown in Fig. 134. Take the reading of the ammeter. Reverse the commutator and obtain the reading on the opposite side of zero. Take the mean of these two readings.

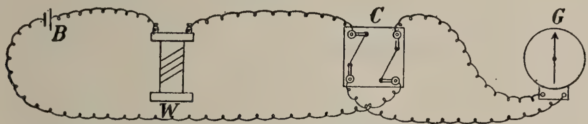


Fig. 134.—Connections for finding the resistance of the wire *W* by the method of substitution.

Then remove the coil, and in its place put a resistance box, and adjust the resistance until the ammeter gives the same reading as before. The resistance now used must of course be equal to that of the coil. It will be convenient, in arranging the apparatus, to have a key, so that the battery may be put in circuit only when it is needed, and also to arrange the connections so that you can change from the coil to the resistance box very easily. Find the resistance of the three coils.

Next, find the resistance of the two coils of fine wire (1) when joined in series, (2) when joined in parallel.

Repeat your measurements and take the mean of your results.

The laws of resistance of wires state that the resistance varies (1) directly as the length, (2) inversely as the cross-section. (TEXT-BOOK, § 534.) Are these laws verified by your measurements? (Calculate from your measurements of the resistance of the coils singly what the resistance in series and in parallel should be, and state your results.)

NOTE.—For measuring high resistances a milli-ammeter or a galvanometer should be used.

Experiment 122.—To find the resistance of a wire by the Wheatstone bridge. (TEXT-BOOK, §§ 532, 533.)

APPARATUS:—Slide wire bridge (Fig. 135), unknown resistance x, galvanometer or low range voltmeter S, resistance box R, dry cell T, key K, connected as shown in the diagram. In place of the resistance box R a 10-ohm coil can be used to measure resistances ranging from about 1 to 100 ohms with a fair degree of accuracy.

Method.—Make an estimate of the resistance of x and pull out plugs in R corresponding to this number of ohms.

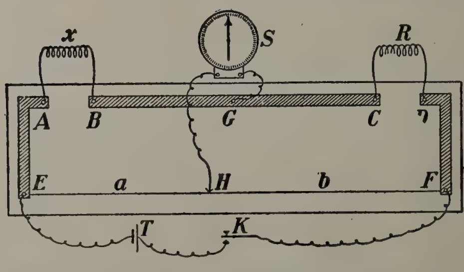


FIG. 135.—Diagram of a form of Wheatstone bridge.

Make contact at H by pressing the slider H, and then press the key K. There will probably be a throw of the galvanometer needle. Vary the position of H until there is no deflection when the contact is made. If necessary, change the resistance in R until the balance is obtained.

Then measure a and b, the distances of H from E and F. From the principle of the Wheatstone bridge (Ohm's Law)

$$\frac{x}{R} = \frac{a}{b}, \text{ or } x = \frac{a}{b}R,$$

from which x is at once obtained.

For the best results a should not differ greatly from b.

Measure the resistance of an electric bell, a telegraph sounder, an electric lamp, or any other electrical appliance.

***Experiment 123.—To calculate the power required to operate an electric toaster (or other electrical appliance).** (TEXT-BOOK, §§ 543, 544.)

APPARATUS:—Toaster, ammeter (range 0-10 amperes), voltmeter (range 0-150 volts), connecting wires, 10-ampere fuse, source of current (110 volts).

Method.—Connect the apparatus as in Fig. 136 and note the readings of the ammeter and voltmeter at one-minute

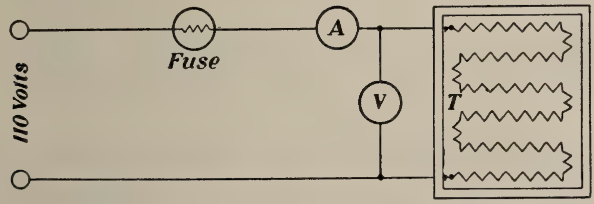


FIG. 136.—Finding the power required to operate an electric toaster. *A*, ammeter: *V*, voltmeter: *T*, toaster.

intervals for five minutes. Multiply the number of volts by the number of amperes in each case to find the number of watts of power. Find the average power being used.

QUESTION.—If the toaster were kept in operation for two hours how many kilowatt-hours of electrical energy would be used? What would be the cost at 5c. per k. w. h.?

Experiment 124.—To compare the power required to operate a 32 c.p. carbon lamp with that required to operate a 60-watt tungsten lamp and to calculate the number of watts per c.p. in each case. (TEXT-BOOK, § 544.)

APPARATUS:—32 c.p. carbon and 60-watt tungsten lamps in good condition, low range ammeter, 0-150 volt voltmeter, paraffin-block photometer.

Method.—Find the average power in watts required to operate each lamp by the method given in Experiment 123.

Next darken the room and place the lamps on opposite sides of the paraffin-block photometer (Fig. 137). Adjust the distances until the two blocks are equally illuminated and calculate the candle-power of the tungsten lamp on the assumption that the power of the carbon lamp is 32 c.p.*

Find the number of watts per c.p. in each case.

Why are carbon filament lamps not used extensively for lighting purposes?

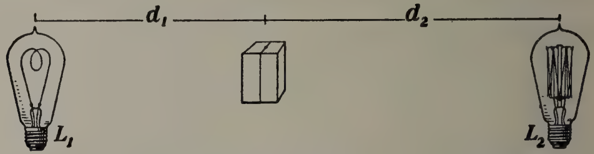


FIG. 137.—Comparison of a carbon lamp and a tungsten lamp.

****Experiment 125.—To find the number of joules (watt-seconds) of energy required to develop 1 calorie of heat.** (TEXT-BOOK, §§ 286, 546.)

APPARATUS:—Carbon lamp (8 or 16 c.p.), 0-150 volt voltmeter, low range ammeter, calorimeter, thermometer.

Method.—Weigh the calorimeter, add enough water at a few degrees below room temperature to cover the glass part of the lamp when it is placed in the calorimeter and weigh again.

---

*Standard 32 c.p. carbon lamps can be purchased, but the principle is demonstrated equally well by using an ordinary 32 c.p. lamp.

Connect the lamp, ammeter and voltmeter as in Fig. 138 and place the lamp in position in the calorimeter. Take the temperature carefully, note the time and turn on the current. Keep the water stirred with the thermometer and let the current flow until the temperature of the water is as much above room temperature as it was below at the beginning of the experiment. Note the readings of the voltmeter and ammeter every minute and calculate the average power in watts. Note the temperature and the time when the current is turned off.

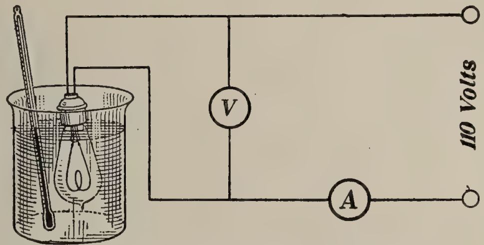


FIG. 138.—Finding the mechanical equivalent of heat.

Calculate the number of calories of heat gained by the calorimeter and water and also the number of watt-seconds (joules) of electrical energy used. Divide the latter by the former.

The number of watt-seconds per calorie is called the *Mechanical Equivalent of Heat.*

****Experiment 126.—To test the power and the efficiency of an electric motor.** (TEXT-BOOK, § 543.)

APPARATUS:—Small D.C. electric motor ($\frac{1}{8}$ to $\frac{1}{4}$ h. p.), source of direct current, ammeter (0-10), voltmeter (0-150), two spring-balances (0-1,000 gm.), cord or piece of sewing-machine belt to act as brake, revolution counter.

Method.—Arrange the apparatus as in Fig. 139. Measure the circumference of the pulley in cm. and adjust the support which carries the balances until they register about 200 gm. Turn on the current and note the reading of the balances. Hold the revolution counter against the end of the shaft of

the motor for 30 seconds and compute the number of revolutions per second. Note also the readings of the ammeter and voltmeter.

Next alter the initial tension of the balances and repeat the experiment. Do this for at least five readings, one of which should be at the rated speed of the motor, two below the rated speed (*i.e* with an over-load on the motor) and two above the rated speed.

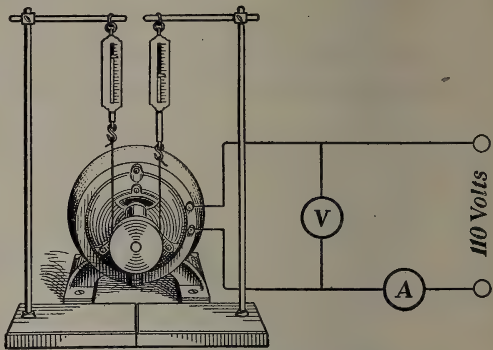


FIG. 139.—Testing an electric motor.

Tabulate results as follows:—

Output

CIRCUMF'RENCE (cm.)	1ST BALANCE (gm.)	2ND BALANCE (gm.)	FRICTION (dynes)	REVS. (per sec.)	POWER (watts)

Input

VOLTMETER (volts)	AMMETER (amperes)	POWER (watts)

For Output,

$$\text{Power (watts)} = \frac{F\ \text{(dynes)} \times \text{Circum. (cm.)} \times \text{Revs. (per sec.)}}{10^7}$$

For Input,

$$\text{Power (watts)} = \text{Volts} \times \text{Amperes.}$$

$$\text{Then the efficiency} = \frac{\text{Output}}{\text{Input}} \times 100\%.$$

Calculate the efficiency in each of the five cases tested. At what speed was the motor most efficient? What happened to the electrical energy which was not changed to mechanical energy?

Find the h.p, developed in each of the five cases.

NOTE.—The output of an A.C. motor can be determined by the same method, but to find the input another method must be used.

****Experiment 127.—To test the accuracy of a watt-hour meter.** (TEXT-BOOK, § 545.)

APPARATUS:—Watt-hour meter*, ammeter (0-10), voltmeter (0-150), bank of lamps in multiple, electric toaster or other non-inductive appliance to serve as load, source of current (110 volts).

Method.—Connect the 110-volt terminals to the "line" side

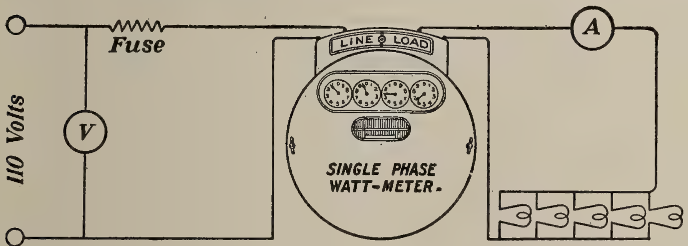


FIG. 140.—Testing a watt-hour meter.

of the meter and join the ammeter in series with the bank of

*Used meters can often be obtained from electric light companies at a low price. These are generally A.C. instruments and must be used on the A.C. mains, in which case the ammeter and voltmeter must also be A.C. instruments.

lamps or toaster to the "load" side of the instrument. The voltmeter is connected directly to the 110-volt terminals (Fig. 141).

Read the meter carefully, note the time and turn on the current. Take readings of the ammeter and voltmeter every five minutes for at least 30 minutes. Note the time when the current is turned off and read the meter again. Calculate the average power in watts and from this the number of k.w.h. of electrical energy used in the time the current was flowing. Compare this with the change in the meter readings.

Tabulate results as follows:—

Time	Voltmeter	Ammeter	Power
0 min.	volts	amp.	watts
5 "			
10 "			
15 "			
20 "			
25 "			
30 "			
		Average power	watts

Calculated energy used............ k.w.h.
Difference in meter readings...... k.w.h.
Error in meter.................... per cent.

APPENDIX

Information and Suggestions for Teachers

Size of Classes

Experience has shown that the most efficient way to teach laboratory physics in the secondary school is to have all the students perform the same experiment at the same time. In this case it is possible for a teacher to supervise a class of twenty-four, working usually in pairs. If the class is larger, it should be divided into two sections for laboratory work. Sometimes three or more are assigned to the same apparatus, but this is unsatisfactory, as those not actually doing the work generally become passive observers and lose interest in the experiment. Result: confusion and wasted time.

Correlation of Laboratory Work and Class Recitations

For the laboratory work to be of the highest value it should be closely related to the instruction given in class. *The experiment should be preceded and also followed by class discussions.* The discussion which precedes each experiment should bring out the reason for the investigation, and in it the student should be encouraged to suggest possible methods of attacking the problem. The final discussion should emphasize the results obtained, point out probable sources of error and show that the experiment is an essential part of the subject.

How Much Laboratory Work?

The most valuable experiments for individual work are those which demand actual measurements and which yield quantitative results. Simple qualitative experiments should ordinarily be demonstrated by the teacher.

Assuming that there are four periods devoted to physics each week, one of them should be spent in the laboratory. At the rate of one per week the students will be able to cover

approximately fifty experiments in the two years spent in this course in the Middle School.

If the work is planned well beforehand and the apparatus got in readiness, almost any experiment in this MANUAL can be performed in a single period. A high degree of accuracy in the quantitative results, though desirable in advanced work, cannot be expected from students in this grade in the limited time available. On the other hand the teacher should promptly check any tendency to do careless work.

NOTE-BOOKS

These should be properly supervised; otherwise they lose much of their value. When well kept, they inculcate habits of neatness and orderly expression, and the act of recording the details of the experiment serves to fix in the student's memory the laws or conclusions developed in it. For the first two or three experiments the students will need some guidance in preparing their reports, but as soon as possible they should be left to their own resources, except for occasional suggestions.

Prompt correction of the reports is necessary, especially at the beginning. Reports should not be allowed to accumulate, but should be examined and returned to the student so that he may, while the experiment is still fresh in his mind, learn wherein his procedure was unsatisfactory. When loose-leaf books are used, the loose sheets containing the experiment may be handed in while the rest of the book is retained for any experiments which may be done before the reports are returned.

A considerable portion of the term marks should be given for experimental work, and in valuing it neatness and punctuality, as well as accuracy and ability in handling the apparatus, should be considered.

APPARATUS

In equipping a laboratory a teacher always has difficulty in deciding what apparatus to buy first. A safe rule to follow is to consider carefully the *teaching value* of any piece of

apparatus before ordering it. For example, an optical disc will be used in more experiments than will a spectroscope; and if there is a choice between twelve low range voltmeters and an equal number of telegraph sets, one should not hesitate to choose the former.

Poorly constructed apparatus should be avoided, even though its initial cost is less. It will be a source of continual trouble and will not be economical in the end. Apparatus may be inexpensive and yet good, but cheap things should be viewed with suspicion.

A fairly complete list of useful apparatus for experimental work by Lower and Middle School students is given below. The number of pieces is based on the assumption that there are twenty-four in the class.

LIST OF APPARATUS

I. Measurement and Mechanics.

Expt. 16,	12 Metre sticks.
" 1, 3, etc.	24 12-inch rules (in. and cm.).
" 3, 5, etc.	24 Callipers (inside and outside).
" 3, 5, etc.	24 Wooden cylinders (about 8 cm. high × 5 cm. diam.).
" 29, 30	12 Aluminium cylinders. (7 cm. high × 4 cm. diam.).
" 29, 30	12 Iron cylinders. (5 cm. high × 4 cm. diam.).
" 29	12 Pieces of granite.
" 7	24 Pieces of glass tubing (about 15 cm. long × 3 cm. diam.).
" 7	24 Rubber corks for above.
" 16	12 Sliding knife-edges to fit metre sticks.
" 5, 6, etc.	12 Graduates (200 c.c.).
" 8, 9, etc.	12 Balances with metric weights (should read to 1 cg.).
" 16	12 Spring-balances (0–1000 gm.).
" 5, 6, etc.	24 Overflow cans (about 500 c.c.).
" 5	24 Catch-buckets (about 200 c.c.).
" 11, 57	12 Specific gravity bottles.
" 11	12 Hydrometers (such as used in battery testers).
" 36	12 Files (three-cornered).
" 38	12 Capillary tubes (1 metre long × 1 mm. diam.).
" 2, 4, etc.	Supply of squared paper.

Measurement and Mechanics—*Continued*

Expt. 6	24 Spheres for volume measurement.
" 9	24 Rectangular blocks of wood (about 4 × 5 × 6 cm.).
" 31	12 Lead sinkers.
" 35	Supply of burned-out electric lamps.
" 36	12 Glass U-tubes (about 40 cm. high).

II. Sound.

Expt. 44	12 Tuning forks (C 256) unmounted.
" 44	12 Brass tubes for resonance (about 15 in. long × 1¼ in. diam.).
" 44	12 Brass tubes to fit inside the above.
" 50	24 Deep wide-mouthed bottles.
" 50	24 Glass plates (about 2 × 3 in.).

Note:—Sound does not lend itself readily to individual experiments by the pupils. Most of the experiments should be demonstrated by the teacher.

III. Heat.

Expt. 53, 54, etc.	12 Bunsen burners (or spirit lamps if gas not available).
" 53, 54, etc.	12 Retort stands with rings.
" 53, 54, etc.	12 Sheets asbestos gauze.
" 60, 61, etc.	12 Beakers (600 c.c.).
" 60, 61, etc.	24 Beakers (400 c.c.).
" 53, 54, etc.	12 Florence flasks (300 c.c.), with 2-hole corks.
" 53, 54, etc.	12 Centigrade thermometers (–20° C to 110° C).
" 61, 62, etc.	12 Calorimeters.
" 62	12 Lbs. copper shot.
" 62	12 Lbs. lead shot.
" 54	12 Brass tubes (105 cm. long × 6 mm. in diam.).
" 54	12 Levers for above.
" 70	12 Polished metal cups.
" 59	12 Capillary tubes for Charles' Law.
" 69	12 Steam traps.
" 56	24 Small Florence flasks or spherical bottles, complete with corks and tubes.
" 59	12 Tall jars (about 35 cm. high × 6 cm. diam.).
" 67	Supply of test-tubes (small).
" 62	Supply of test-tubes (large).
" 66	12 Tumblers.
	12 Yards rubber tubing.
	12 Lbs. glass tubing (¼ in. in diam.).

IV. Light.

Expt. 75	12 Pin-hole cameras.
" 77, 83, etc.	12 Screens (about 6 in. square).
" 78, 86, etc.	6 Packets large pins.
" 84, 85, etc.	24 Hat pins.
" 84, 85, etc.	24 Rubber corks (large).
" 78, 79	24 Plane mirrors (2 cm. × 10 cm.).
" 80, 81, etc.	24 " " (10 cm. × 15 cm.).
" 83, 84	12 Concave mirrors (f = 25 cm.).
" 85	12 Convex mirrors (f = 25 cm.).
" 87, 88, etc.	12 Converging lenses (f = 20 cm.).
" 89, 90, etc.	12 Diverging lenses (f = 25 cm.).
" 86	12 Rectangular blocks of glass (about 1.5 × 6 × 10 cm.).
" 78, 79, etc.	24 Protractors (celluloid).
" 78, 79, etc.	24 Soft wood boards (12 × 12 × ½ in.).
" 91	12 Equilateral prisms (about 4 cm. side).
" 92	12 Linen testers.
" 77, 81, etc.	12 Candlesticks.
" 77, 81, etc.	24 Paraffin candles.
" 77, 83, etc.	12 8 c.p. carbon filament lamps.
" 77, 83, etc.	12 16 c.p. " " "
" 77, 83, etc.	12 32 c.p. " " "
" 77, 83, etc.	12 Porcelain lamp sockets on wooden bases.
" 77, 83, etc.	12 Covers for lamps (wooden boxes about 4 × 4 × 7 in. with rectangular opening in side).
" 83, 84, etc.	12 Lens or mirror stands.

V. Electricity and Magnetism

Expt. 98, 99, etc.	12 Pairs of bar magnets with keepers (in boxes).
" 99	12 Horse-shoe magnets.
" 99	12 Shakers for iron filings.
" 99	12 Lbs. iron filings.
" 98, 103, etc.	24 Small compasses.
" 100	24 Knitting-needles.
" 112	24 Bars of soft iron (6 in. long).
" 102	12 Flask electroscopes.
" 102	12 Glass friction rods.
" 102	12 Ebonite friction rods.
" 102	12 Pieces of silk.

Electricity and Magnetism—*Continued*

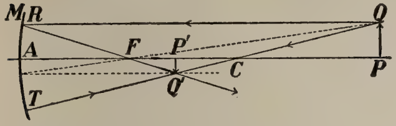
Expt. 102	12 Pieces of flannel.
" 102	12 Proof planes.
" 102	12 Pairs condenser plates.
" 102	12 Sticks of sealing-wax.
" 102	12 Slabs of ebonite for insulating condenser plates.
" 104, 105, etc.	12 Sets of elements for simple cells (8 elements).
" 104	12 Galvanoscopes.
Connections, etc.	12 Spools (small) No. 22 D. C. C. wire.
" 107, 112, etc.	12 Dry cells.
" 111	24 Lead plates.
" 111, 112, etc.	12 Small storage cells.
" 106, 107, etc.	12 Daniell cells (small).
" 105, 111, etc.	12 *Voltmeters (zero centre, 3–0–3 volts).
" 115, 120, etc.	12 *Ammeters (zero centre, 3–0–3 amperes).
" 107	12 Simple apparatus for electrolysis of water.
" 108, 109	24 Copper plates for copper voltameters ($2 \times 3\frac{1}{2}$ in.).
Expt. 120, 121, etc.	12 10-ohm resistance spools.
" 122	12 Simple slide-wire bridges.
" 120, 121, etc.	1 spool manganin or German silver wire to make unknown resistances.
" 115, 123, etc.	12 Porcelain sockets (for fuses).
" 115, 123, etc.	24 3-ampere fuses.
" 116, 117	12 Primary coils (for induction).
" 117	12 Secondary coils (for induction).
" 117	12 Bars soft iron (for above).
" 104, 109, etc.	24 Slotted terminals to fit on plates.
" 118	12 St. Louis motors.
" 102	12 Sheets mica (5×5 in.).
" 102	12 Sheets ebonite (5×5 in.).
" 111, 113	12 Electric bells.
" 115, 120, etc.	12 10-ohm circular rheostats.
" 115	1 spool 3-ampere fuse wire.

*A good voltmeter or ammeter costs at least ten dollars. The voltmeter can be used for measuring the E. M. F. of cells and for experiments on fall of potential; it will take the place of a galvanometer in experiments on induction and on finding resistance by using the Wheatstone bridge. These instruments are almost essential for a proper working knowledge of electrical measurements, but should not be put into the hands of students until they understand thoroughly the precautions to be taken in using them.

Note:—Certain pieces of apparatus such as beakers, electric lamps, etc., serve in two or more subjects. Such items have been mentioned only once in the foregoing list.

Proof of Formulas for Spherical Mirrors and Lenses

I. For Mirrors. Let PQ be the object, $P'Q'$ its image, $AP = p$, $AP' = p'$, $AC = r = 2f$.



The triangles $Q'P'C$, QPC are similar, hence

$$\frac{P'Q'}{PQ} = \frac{P'C}{PC} = \frac{r - p'}{p - r} \ldots .(1).$$

Again, considering AR to be a straight line perpendicular to AF, we have $PQ = AR$; and as the triangles $Q'P'F$, RAF are similar,

$$\frac{P'Q'}{AR} = \frac{FP'}{FA} = \frac{p' - \frac{1}{2}r}{\frac{1}{2}r} = \frac{2p' - r}{r} \ldots .(2).$$

From (1) and (2) $\qquad \dfrac{r - p'}{p - r} = \dfrac{2p' - r}{r}.$

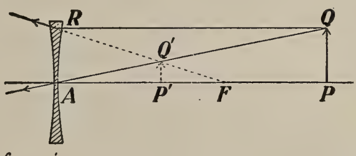
Simplifying this equation, and dividing through by $pp'r$ we obtain

$$1/p + 1/p' = 2/r.$$

In this case P, P' and C are all on the right of A. By considering all lines from A measured to the right to be "+," and all to the left to be "−," this formula holds for all positions of the object and also for a convex mirror.

For example, if (in Experiment 85) $p = +40$ cm, $p' = -8$, then from the formula, $r = -20$ cm., *i.e.*, it is a convex mirror of radius 20 cm.

II. For Lenses. Take a concave lens, and let $AP = p$, $AP' = p'$, and $AF = f$.



From the similar triangles QAP, $Q'AP'$, $\dfrac{P'Q'}{PQ} = \dfrac{AP'}{AP} = \dfrac{p'}{p} \ldots .(1).$

Again, $AR = PQ$, and from the triangles $FP'Q'$, FAR, $\dfrac{P'Q'}{AR} = \dfrac{FP'}{FA} = \dfrac{f - p'}{f} \ldots .(2).$

From (1) and (2) $\qquad \dfrac{p'}{p} = \dfrac{f - p'}{f}.$

Simplifying and dividing through by $pp'f$ we obtain $1/p' - 1/p = 1/f$.

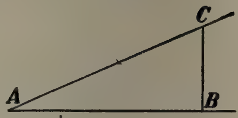
This formula holds for all positions of the object and also for a convex lens.

For example, if (in Experiment 88) $p = +60$ cm., $p' = -20$ cm., then from the formula, $f = -15$, *i.e.*, it is a convex lens of focal length 15 cm.

Sines and Tangents

From C, any point in AC, draw CB perpendicular to AB. Then, by definition,

Sine of angle $CAB = BC/AC$,
Tangent of angle $CAB = BC/AB$.



Angle	Sine	Tangent	Angle	Sine	Tangent	Angle	Sine	Tangent
°			°			°		
0	0.000	0.000	31	0.515	0.601	62	0.883	1.881
1	0.017	0.017	32	0.530	0.625	63	0.891	1.963
2	0.035	0.035	33	0.545	0.649	64	0.899	2.050
3	0.052	0.052	34	0.559	0.675	65	0.906	2.145
4	0.070	0.070	35	0.574	0.700	66	0.914	2.246
5	0.087	0.087	36	0.588	0.727	67	0.921	2.356
6	0.105	0.105	37	0.602	0.754	68	0.927	2.475
7	0.122	0.123	38	0.616	0.781	69	0.934	2.605
8	0.139	0.141	39	0.629	0.810	70	0.940	2.747
9	0.156	0.158	40	0.643	0.839	71	0.946	2.904
10	0.174	0.176	41	0.656	0.869	72	0.951	3.078
11	0.191	0.194	42	0.669	0.900	73	0.956	3.271
12	0.208	0.213	43	0.682	0.933	74	0.961	3.487
13	0.225	0.231	44	0.695	0.966	75	0.966	3.732
14	0.242	0.249	45	0.707	1.000	76	0.970	4.011
15	0.259	0.268	46	0.719	1.036	77	0.974	4.331
16	0.276	0.287	47	0.731	1.072	78	0.978	4.705
17	0.292	0.306	48	0.743	1.111	79	0.982	5.145
18	0.309	0.325	49	0.755	1.150	80	0.985	5.671
19	0.326	0.344	50	0.766	1.192	81	0.988	6.314
20	0.342	0.364	51	0.777	1.235	82	0.990	7.115
21	0.358	0.384	52	0.788	1.280	83	0.993	8.144
22	0.375	0.404	53	0.799	1.327	84	0.995	9.514
23	0.391	0.424	54	0.809	1.376	85	0.996	11.43
24	0.407	0.445	55	0.819	1.428	86	0.998	14.30
25	0.423	0.466	56	0.829	1.483	87	0.999	19.08
26	0.438	0.488	57	0.839	1.540	88	0.999	28.64
27	0 454	0.510	58	0.848	1.600	89	1.000	57.29
28	0.469	0.532	59	0.857	1.664	90	1.000	Infinity
29	0.485	0.554	60	0.866	1.732			
30	0.500	0.577	61	0.875	1.804			

Metric Equivalents

1 in. = 2.54 cm.	1 cm. = 0.3937 in.
1 ft. = 30.48 cm.	1 m. = 39.37 in.
1 yd. = 91.44 cm.	1 m. = 1.094 yd.
1 mi. = 1.609 km.	1 km. = 0.6214 mi.
1 sq. in. = 6.4514 sq. cm.	1 sq. cm. = 0.1550 sq. in.
1 sq. ft. = 929.01 sq. cm.	1 sq. m. = 10.764 sq. ft.
1 sq. yd. = 0.83613 sq. m.	1 sq. m. = 1.196 sq. yd.
1 cu. in. = 16.387 c.c.	1 c. c. = 0.061 cu. in.
1 cu. ft. = 28317 c.c.	1 l. = 61.024 cu. in.
1 cu. yd. = 0.7645 cu. m.	1 cu. m. = 1.308 cu. yd.
1 Imp. gal. = 4.546 l.	1 l. = 1.7598 Imp. pts.
1 lb. av. = 453.59 g.	1 kg. = 2.205 lb. av.
1 gr. = 0.0648 g.	1 g. = 15.432 gr.

Densities of Substances, in Grams per Cubic Centimetre

Alcohol, ethyl	0.791	Lead, cast or wrought	11.34
Alcohol, methyl	0.810	Maple (average)	0.68
Aluminium, cast	2.56	Marble	2.65
Aluminium, wrought	2.72	Mercury	13.60
Benzine	0.90	Nickel	8.60
Bismuth	9.80	Oak (average)	0.75
Brass wire (70 Cu + 30 Zn)	8.70	Paraffin	0.89
Cadmium, cast	8.56	Petroleum	0.878
Cedar. (average)	0.53	Pine, white (average)	0.42
Cobalt, cast	8.60	Pine, red (average)	0.59
Cork. (average)	0.24	Platinum	21.45
Copper, cast	8.88	Sea-water	1.025
Copper, wrought	8.90	Silver, cast	10.45
Diamond	3.5	Silver, wrought	10.56
Glycerine	1.26	Steel, wire	7.85
Gold, wrought	19.34	Sulphuric acid	1.84
Ice	0.90	Tin, cast	7.29
Iridium	22.10	Tungsten	19.12
Iron, gray cast	7.08	Uranium	18.49
Iron, wrought	7.85	Zinc, cast	7.10

Weight in Grams of One Cubic Metre of Saturated Water Vapour

Temp.	Weight	Temp.	Weight	Temp.	Weight
—5° C.	3.26 gm.	7° C.	7.75 gm.	19° C.	16.31 gm.
—4	3.53	8	8.27	20	17.30
—3	3.83	9	8.82	21	18.34
—2	4.14	10	9.40	22	19.43
—1	4.48	11	10.02	23	20.58
0	4.85	12	10.66	24	21.78
1	5.19	13	11.35	25	23.05
2	5.56	14	12.07	26	24.38
3	5.95	15	12.83	27	25.77
4	6.36	16	13.64	28	27.23
5	6.80	17	14.48	29	28.76
6	7.26	18	15.37	30	30.37

TABLE GIVING RELATIVE HUMIDITY

Reading of Dry Thermometer (Fahr.)	Reading of wet thermometer (Fahr.)																	
	70	69	68	67	66	65	64	63	62	61	60	59	58	57	56	55	54	53
80	61	57	54	51	47	44	41	38										
79	63	60	57	54	50	47	44	41	37									
78	67	64	60	57	53	50	46	43	40	37								
77	71	67	63	60	56	52	49	46	42	39	36							
76	74	70	67	63	59	55	52	48	45	42	38	35						
75	78	74	70	66	63	59	55	51	48	44	40	38	34					
74	82	78	74	70	66	62	58	54	51	47	43	40	37	34				
73	86	82	78	73	69	65	61	58	54	50	46	43	40	36	33			
72	91	86	82	78	73	69	65	61	57	53	49	46	42	39	35	32		
71	95	90	86	82	77	73	69	64	60	56	53	49	45	41	38	34	31	
70		95	90	86	81	77	72	68	64	60	56	52	48	44	40	37	33	30
69			95	90	86	81	77	72	68	64	59	55	51	47	44	40	36	32
68				95	90	85	81	76	72	67	63	59	55	51	47	43	39	35
67					95	90	85	80	76	71	67	62	58	54	50	46	42	38
66						95	90	85	80	76	71	66	62	58	53	49	45	41
65							95	90	85	80	75	70	66	62	57	53	48	44
64								95	90	85	79	75	70	66	61	56	52	48
63									95	90	84	79	74	70	65	60	56	51
62										94	89	84	79	74	69	64	60	55
61											94	89	84	79	74	68	64	59
60												94	89	84	78	73	68	63

Velocity of Sound, in Metres per Second

Air at 0° C	332	Pine, along fibre	3320
Aluminium	5104	Carbon dioxide	261.6
Brass	3500	Hydrogen	1278
Copper	3560	Illuminating gas	490
Iron	5130	Water at 3.9° C	1399
Glass	5000 to 6000	" " 13.7° C	1437

Coefficients of Linear Expansion

Aluminium	0.0000 2313	Nickel	0.0000 1279
Brass	0.0000 1900	Platinum	0.0000 0899
Copper	0.0000 1678	Silver	0.0000 1921
Glass	0.0000 0899	Steel	0.0000 1322
Gold	0.0000 1443	Tin	0.0000 2234
Iron, soft	0.0000 1210	Zinc	0.0000 2918

Specific Heats

Aluminium	0.214	Ice at − 10° C.	0.50	Paraffin	0.694
Brass	0.090	Iron	0.113	Petroleum	0.511
Copper	0.094	Lead	0.031	Platinum	0.032
Glass, crown	0.16	Marble	0.216	Silver	0.056
Gold	0.032	Mercury	0.033	Zinc	0.093

Indices of Refraction, for Sodium Light

Crown glass	1.514 to 1.560	Hydrochloric acid, at 20° C.	1.411
Flint glass	1.608 to 1.792	Nitric acid, at 20° C.	1.402
Rock salt	1.544	Sulphuric acid, at 20° C.	1.437
Sylvine (potassium chloride)	1.490	Oil of turpentine, at 20° C.	1.472
Fluor spar	1.434	Ethyl alcohol, at 20° C.	1.388
Diamond	2.42 to 2.47	Carbon bisulphide	1.628
Canada Balsam	1.528	Water, at 20° C.	1.334

Critical Angles

Water	$48\frac{1}{2}$°	Crown glass	$40\frac{1}{2}$°	Carbon bisulphide	38°
Alcohol	$47\frac{1}{2}$	Flint glass	$36\frac{1}{2}$	Diamond	$42\frac{1}{2}$

Specific Resistance and Resistance per Mil-foot

Specific Resistance is the resistance of a cube of the material, whose edge is 1 cm., when a current flows parallel to one of the edges.

1 mil = 1/1000 inch; 1 mil-foot = 1 ft. long and 1 mil in diameter.

Specific Resistance is given in microhms, or millionths of an ohm. Resistance per mil-foot is in ohms. Temperature is 20° C. unless otherwise stated.

Substance	Sp. R.	M.-ft.	Substance	Sp. R.	M. -ft.
Aluminium wire.......	2.83	17.0	Chromium.......	2.6	15.6
Carbon (filam't) 0° C.	3500	21,054	Nickel..........	7.8	46.9
" " 1500° C.	1500	9,023	Nichrome wire...	100	602
Copper wire.........	1.72	10.4	Platinum wire....	10	60.2
German Silver.......	21	126	Silver wire.......	1.63	9.8
Iron wire............	10	60	Tungsten, 20° C..	5.5	33.1
Steel rails...........	11.9	71.6	" 1727° C..	59	357
Mercury.............	95.8	576	" 3227° C..	118	710

Resistance at 0° C. of Copper Wire (Brown and Sharpe Gauge)

Gauge No.	Diam. in mm.	Section in sq. mm.	Ohms per 1000 m.	Gauge No.	Diam. in mm.	Section in sq. mm.	Ohms per 1000 m.
0000	11.68	107.2	0.1519	19	0.912	0.653	24.95
000	10.40	85.03	.1915	20	.812	.518	31.46
00	9.27	67.43	.2415	21	.723	.410	39.67
0	8.25	53.48	.3045	22	.644	.326	50.02
1	7.35	42.41	.3840	23	.573	.258	63.08
2	6.54	33.63	.4842	24	.511	.205	79.54
3	5.83	26.67	.6106	25	.454	.162	100.3
4	5.19	21.15	.7699	26	.405	.129	126.5
5	4.62	16.77	.9709	27	.361	.102	159.5
6	4.12	13.30	1.224	28	.321	.081	201.1
7	3.66	10.55	1.544	29	.286	.064	253.6
8	3.26	8.37	1.947	30	.255	.051	319.8
9	2.91	6.63	2.455	31	.227	.040	403.2
10	2.59	5.26	3.095	32	.202	.032	508.4
11	2.30	4.17	3.903	33	.180	.025	641.1
12	2.05	3.31	4.922	34	.160	.020	808.5
13	1.83	2.62	6.206	35	.143	.016	1019
14	1.63	2.08	7.826	36	.127	.013	1286
15	1.45	1.65	9.868	37	.113	.010	1621
16	1.29	1.31	12.44	38	.101	.008	2044
17	1.15	1.04	15.69	39	.090	.006	2578
18	1.02	0.82	19.79	40	.080	.005	3250